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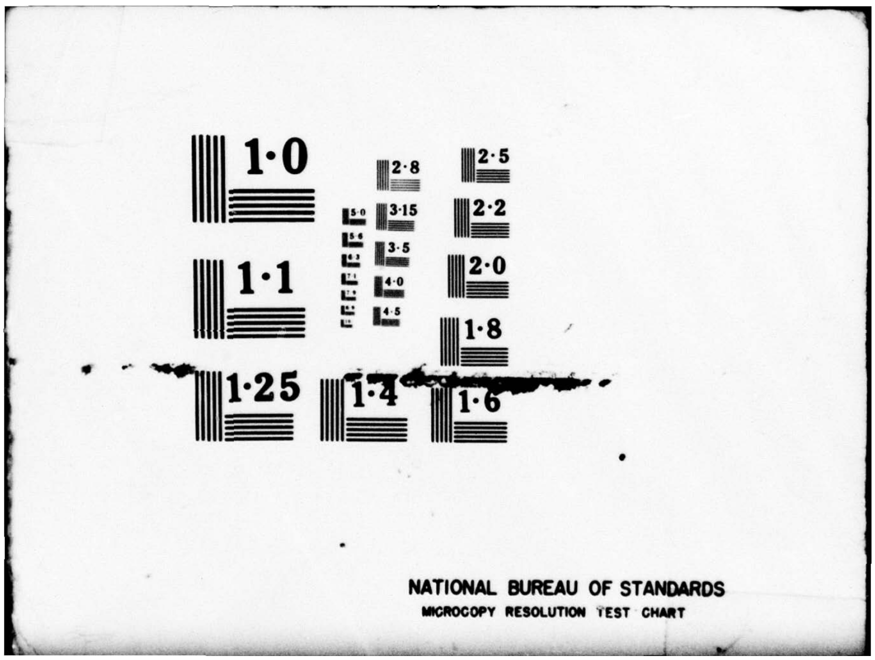
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# AIR FORCE HUMAN RESOURCES LABORATORY

## EFFECTS OF PLATFORM MOTION, VISUAL AND G-SEAT FACTORS UPON EXPERIENCED PILOT PERFORMANCE IN THE FLIGHT SIMULATOR


By

Philip A. Irish, III, 1st Lt, USAF
George H. Buckland, Capt, USAF

FLYING TRAINING DIVISION
Williams Air Force Base, Arizona 85224



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Final Report for Period April 1976 – March 1977




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## NOTICE



This final report was submitted by Flying Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224, under project 1123, with HQ Air Force Human Resources Laboratory (AFSC), Brooks Air Force Base, Texas 78235.



This technical report has been reviewed and is approved for publication.

EDWARD E. EDDOWES, Technical Advisor
Flying Training Division

DAN D. FULGHAM, Colonel, USAF
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The objective of this study was to empirically assess the performance of experienced pilots in the Advanced Simulator for Pilot Training (ASPT) under varying platform motion, G-seat, field-of-view and ceiling/visibility conditions. Five experienced T-37 pilots flew five contact and instrument maneuvers in the ASPT under all combinations of the independent variables. Automated performance measures based on system parameters, pilot inputs and derived scores were collected and analyzed. The results indicated that expert performances were affected by the motion, field-of-view and ceiling/visibility variables and were often manifested as changes in control behavior rather than vehicle performance.

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## PREFACE

This report covers research conducted by the Flying Training Division of the Air Force Human Resources Laboratory between April 1976 and March 1977. Full support of this project was provided by the 82d Flying Training Wing, Williams AFB, Arizona 85224. The project was conducted in support of project 1123, Flying Training Development, Mr. James F. Smith, project scientist; task 112303, Exploitation of Flight Simulation in Undergraduate Pilot Training (UPT), Mr. Robert R. Woodruff, task scientist; work unit 11230325, Simulator Design Configurations Study 2, Capt George H. Buckland, principal investigator, and Lt Philip A. Irish III, associate investigator.

Special appreciation is extended to the Computational Sciences Division at Brooks AFB for their assistance in the data reduction portion of the project. The authors would also like to extend special thanks to the following individuals for their outstanding contributions to this efforts: Dr. Thomas H. Gray for his critical editorial comments; Lt Paul M. Grunzke for his continuing suggestions; Mr. Thomas Farnan and Capt Richard Dorre for their excellent console operation; Capts Steven Cotterman, John Swofford, Anthony Dennis, Lts Michael Duringer, and Neal Houde for their dedication as subjects.

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# I. INTRODUCTION

## Statement of the Problem

For some time, it has been accepted that the more closely the flight simulator approximates the aircraft in terms of the visual, kinesthetic, vestibular, and control loading cues provided to the pilot, the more effective the simulator will be for training. This hypothesis is based on the assumption that maximum training transfer will occur when the training environment and the transfer environment are identical. Recent developments in the art of flight simulation have provided research and training managers a wide variety of aircraft simulator design configuration options. Available options include synergistic or cascaded platform motion systems, pneumatic or hydraulic G-seat/G-suit arrangements and high resolution, multi-channel visual displays. All of these options have been designed and constructed for the sole purpose of increasing or improving the fidelity or realism of the flight simulator. However, assuming that current devices can produce desired levels of fidelity, the direct and associated costs of some of the present fidelity enhancement systems are formidable. Because of increasing economic constraints and extensive procurement projections, future procurement of simulators will have to include only those options which are able to maximize training potential and minimize cost. It is important, therefore, that the nature of the effects of these devices be fully explored, in order not only to describe the effectiveness of these systems but also to provide sufficient information to make informed procurement decisions regarding the selection of hardware design options.

A logical starting point for such investigations is to assess the responses of expert pilots to various configurations of the design options via their performance in the simulator. By monitoring changes in performance, one can objectively observe those design changes which seem to be most important in facilitating or hindering various aspects of pilot performance. Not only may the occurrence of performance changes be noted, but additionally, sufficient measurements may provide insight into the reasons for such changes. Although information on expert pilot performance in the simulator may or may not be related to the training effectiveness of a simulator or simulation in general, it provides a clearer understanding of the underlying psychological, and, to an extent, physiological processes at work within flight simulation. The information generated in this type of investigation is then useful in conducting further studies oriented toward less experienced and naive student behaviors. Such studies could be transfer of training studies which are normally limited to one or two variables due to experimental constraints. A research strategy employing this sequence of investigations provides an economical approach to the exploration and definition of system oriented variables in simulation research and may allow a significant reduction in the number of univariate transfer of training studies which must be conducted in attempting to describe the effects of these variables adequately in follow-on efforts.

The present study was initiated as a follow-on investigation of a previous exploratory effort. The first project, hereinafter referred to as Study I, was entitled "The Effects of System and Environmental Factors Upon Experienced Pilot Performance in the Advanced Simulator for Pilot Training" (AFHRL-TR-77-13). Study I was conducted to provide a "first look" into the main and interactive effects of platform motion, G-seat and visual display factors upon expert pilot performance on five contact and instrument flight maneuvers performed in the simulator. The purpose of this "first look" was to identify those variables and interactions which produce a significant impact upon expert pilot performance. The specific maneuvers studied were: the 360° overhead traffic pattern, ground controlled approach (GCA), takeoff, the aileron roll, and a slow flight exercise. Several types of dependent measures were utilized in Study I, including system output measures, pilot input measures, and derived scores. System output measures were defined for the most part as root mean square (RMS) deviations from specified parameter criteria during a specified

segment of a maneuver or a series of maneuver segments. Pilot input measures were sampled by collecting analogs to pilot induced forces on the control stick and rudder. Derived scores were time-in-tolerance measures reflecting how well the pilot remained within acceptable tolerances on several parameters simultaneously.

Another important aspect of Study I was that an economical approach to the design and analysis of the project was utilized. Briefly, this consisted of using a fractional factorial design which included higher-order (3rd order and above) interaction confounding. Additionally, a very small sample size (N = 3) was utilized in this exploratory effort. Due to the nature of the experimental design and the importance of the topic area, it was decided that some of the results of the first study should be validated and extended in a follow-on project. The present report documents the findings of this effort and compares and contrasts the results of both projects.

**Background**

A considerable amount of research has been performed on one simulator design option: platform motion systems. Studies investigating this issue have been, for the most part, equivocal in terms of the usefulness of platform motion systems. These systems are designed to provide vestibular and kinesthetic cues to the pilot by moving the platform upon which the cockpit rests. These motion systems are designed to provide directional cue information to the pilot, although it is obvious that prolonged directional cue information is physically limited, due to excursion constraints of each motion system. Presumably, the movements are intended to provide alerting information to the pilot; i.e., information indicative of changes in the status of the simulated aircraft.

Many past studies have reported improvements in pilot performance on various tasks when the simulator included platform motion (Borlace, 1967; Brown, Johnson, & Mungall, 1960; Jacobs, Williges, & Roscoe, 1975; Koonce, 1974; Rathert, Creer, & Sadoff, 1961). However, other studies have reported the converse, i.e., that performance remains stable across conditions of the presence and absence of platform motion (Demaree, Norman, & Matheny, 1965). Two recent training studies investigating the platform motion issue (Gray & Fuller, 1977; Woodruff, Smith, Fuller, & Weyer, 1976) have reported no reliable differences between students trained with simulator platform motion and students trained without platform motion. The first study reported no significant differences in training time between motion/no motion groups for any of the tasks investigated. Those tasks represented basic, advanced contact, instrument and navigation maneuvers which are standard in the T-37 phase of undergraduate pilot training. The second study reported no reliable differences due to motion training in pilots' ability to deliver air-to-surface weapons either in the simulator or in the aircraft.

Study I, which dealt with expert performance, revealed statistically significant motion differences in the performance of selected maneuvers. In this study, motion was consistently found to deleteriously affect the subject pilots' performance in the simulator.

Little systematic research has been conducted on pneumatic G-seat/G-suit systems in part because of the relatively small number of those systems available for research in conjunction with advanced platform motion and visual systems. The G-seat was designed essentially to supplement platform motion systems in providing the pilot additional proprioceptive and haptic cueing in order to improve the fidelity of the simulator. This cueing is generated by the systematic inflation and deflation of a series of pneumatic bellows installed in the backrest, seat pan and thigh panels of the pilot's seat. These bellows cause the pilot's weight to be repositioned on his thighs and buttocks in response to the bellows' activity. The cues provided by the G-seat are also of higher frequency and longer duration than those contributed by platform motion systems.

Taylor, Gerber, Allen, Brown, Cohen, Dunbar, Flexman, Hewitt, McElwain, Pancoe, & Simpson (1969), in a project addressing the effectiveness of G-seat cueing systems, reported that improvements in pilot performance accompanied the addition of G-cueing to the simulator dynamics.

Study I of the present series also indicated that performance improvements occurred when ground controlled approach (GCA) and takeoff maneuvers were attempted under conditions of a fully operative G-seat as compared to performance under inoperative G-seat conditions.

Research dealing with visual factors in aircraft simulator performance has been extensive. Many investigators have directed their efforts toward ascertaining the requirements of one particular aspect of the visual domain, field-of-view. Several studies, Armstrong (1970), Reeder and Kolnick (1964), Roscoe (1951), reported adequate pilot landing performances under conditions of restricted fields-of-view. Roscoe, however, reported that as the field-of-view increased, a corresponding improvement in performance occurred. The remaining studies mentioned above did not report this change in performance as a function of the field-of-view.

The results of Study I of this series showed no significant differences in pilot performance as a function of field-of-view (FOV) on four of the five maneuvers which were explored. The general trend of the data, however, suggested improved performance under larger display fields-of-view as compared to performance under restricted FOV conditions. This trend was somewhat substantiated in the analysis of the fifth maneuver in the study, the aileron roll, In this instance, performance was significantly better under conditions of maximum field-of-view as compared to two levels of restricted visual displays.

There has not been a great deal of research directed at examining possible interactions of the simulator design options. Past research addressing interactive effects of motion and visual cueing devices has been directed primarily toward the psychophysiological issues in simulator training. Specifically, problems of simulator sickness, disorientation and nausea have been the focus of this type of research. There has, in the past, been little information generated on the interactive effects of these cueing devices on pilot performance. Study I addressed this issue and reported several significant interactive impacts upon the pilot performance on selected flight tasks. Significant interactions were found to exist between the platform motion and G-seat systems, motion and visual systems as well as interactions between the cueing devices and experimentally constructed environmental variables, such as, wind, turbulence and ceiling/visibility. These findings stimulate additional research questions regarding the selection of sets of simulator design configuration options.

The results of the past research on these simulator design variables also tend to suggest that these results are highly specific to the simulator being investigated. This is due to differences in the inherent capabilities of the simulation devices and to the differences in the manner of computer programming for each simulator. Furthermore, it is probable that the nature of the effects are also specific to the type of aircraft being simulated as well as the experience levels of the subject pilot populations. Finally, the results of the first study tend to substantiate the hypothesis that the effects of a particular cueing device, both alone and in combination with other devices, may be specific to the type of maneuver being attempted.

**Study II Objectives**

The primary objective of Study II was to assess empirically the performance of experienced T-37 pilots in the Advanced Simulator for Pilot Training (ASPT) under varying platform motion, G-seat, field-of-view, and ceiling/visibility configurations.

Another objective was to further explore the prominent main and interactive effects which were reported in Study I in an attempt to confirm and validate the approach and findings of that study.

Furthermore, it was desired that the investigation of the above-mentioned variables be extended into the area of "higher G-force" maneuvers, representative of a more dynamic flight regime.

Finally, it was desired that additional information regarding the relationships between the system output measures and the pilot input measures as measured by the automated measurement system capability of the ASPT be obtained for various system configurations, flight maneuvers, and simulated environmental conditions.

## Hypotheses

As a result of the findings of the previous study, several *a priori* hypotheses were formulated for this investigation. First, since platform motion consistently produced deleterious effects upon the pilot performances in the first study, it was hypothesized that experienced pilot performance in the simulator would be superior across all maneuvers when flown under no-platform-motion conditions than when under either 3- or 6-degree-of-freedom motion conditions.

Second, although the field-of-view variable produced a significant impact only upon the performance of the aileron roll maneuver in the first study, the consistency in the direction of the nonsignificant results in that study warranted the hypothesis that pilot performance under full field-of-view conditions would be superior to performance under restricted field-of-view conditions for all maneuvers excluding the ground controlled approach where the performances would tend to be equal across the field-of-view conditions. This exclusion was formulated, because the most important visual information in this task was concentrated directly in front of the pilot, and thus decrements in peripheral vision information would not seriously affect the pilot's performance.

Third, it was hypothesized that the variation in the G-seat's operation would not differentially affect performance. Although the G-seat was found to impact the performances on the takeoff and GCA maneuvers in the first study, these differences were not consistent across the broad range of dependent variables and did not warrant a directional hypothesis.

Fourth, it was hypothesized that reducing the ceiling/visibility conditions to minimums would substantially reduce performance on the 360° overhead pattern maneuver. However, it was also hypothesized that this environmental deterioration would not adversely affect performance on the GCA.

One of the most powerful and consistent effects evidenced in Study I was the ceiling/visibility variable. Performance on the overhead landing task was consistently degraded when the maneuver was flown under restricted ceiling/visibility conditions. The same trend was found for the ground controlled approach; however, it was not quite as consistent as in the former maneuver. Because the ground controlled approach was designed as an instrument maneuver to be performed under conditions of reduced ceiling/visibility, and because of the insufficient consistency of this variable's effects on performance in the first study, it was felt that variation in ceiling/visibility would not affect performance on this maneuver.

Finally, no directional hypotheses were made regarding interaction effects. Although the substantiation of the presence and/or absence of specific interactions was of major concern in this study, the investigators believed that the results of the first study were insufficient evidence upon which to base directional hypotheses. This was especially the case for an unusually large three-factor interaction which was found in the former study.

# II. METHOD

## Subjects

Five T-37 instructor pilots (IPs) from Williams Air Force Base were used as subjects for the duration of the effort. Each subject was selected on the basis of flying experience. The flight experience of the subjects ranged from 300 to 2,200 total flying hours, and from 160 to 700 hours in the T-37 aircraft. Each subject was required to be a qualified T-37 IP and to be current in the T-37 at the time of the study.

## Apparatus

The Advanced Simulator for Pilot Training (ASPT) located at the Air Force Human Resources Laboratory/Flying Training Division (AFHRL/FT) was used for the duration of the study.

The ASPT consists of two fully instrumented T-37 cockpits which are mounted on two independent platform motion systems. Each platform motion system has six hydraulically-driven legs which are operated

synergistically to provide six degree-of-freedom (DOF) movement. The platform motion system has the capability of approximately 4-feet horizontal and 3-feet vertical travel. The displacement capabilities include: (a) Pitch: –20 degrees to +30 degrees; (b) Roll: ±22 degrees; and (c) Yaw: ±32 degrees.

The left seats in both cockpits are configured as 31-bellow pneumatic G-seats with variable tension lap belts. The bellows are located on the seat pan (16 cells), the backrest (9 cells), and thigh panels (6 cells). The G-seat operates by way of the programmed inflation and deflation of individual bellow(s) in response to the requirements of each particular maneuver.

The wraparound visual system of the ASPT is comprised of seven 36-inch monochromatic cathode-ray tubes (CRTs) placed in such a manner as to provide the pilot with a visual field-of-view of +110 degrees to –40 degrees vertical and ±150 degrees horizontal. The visual environment is constructed by way of computer generated imagery (CGI). Most prominent ground references (mountains, runways, towers, roads, etc.) within a 100 square nautical mile area of Williams Air Force Base have been modeled within the environment. The visual imagery is updated at a 30 times per second rate in response to the aircraft's movement through the simulated environment. In this study, an enhanced visual environment was utilized, which differed from the normal ASPT configuration in the amount of ground image detail presented to the pilot. This image detail was enhanced by providing more ground section lines and by providing additional objects (stationary aircraft, tractor) in the vicinity of the runway. A detailed discussion of the characteristics of this enhanced environment can be found in Monroe, Rife, Cyrus, & Thompson (1976).

Another capability which the ASPT possesses is the ability to record, store and score various pilot performance parameters automatically. These measures are sampled and stored at an iteration rate ranging from 3.75 to 15 times per second, dependent upon the nature of the measure. The computer system also possesses a Cognitronics voice-generation capability for providing ground-controlled approach information.

All systems of ASPT (platform motion, visual display) can be varied, dependent upon experimental requirements to match a wide variety of environmental conditions or aerodynamic characteristics. For a more comprehensive technical discussion of the ASPT capabilities, consult Hagin and Smith (1974), and Rust (1975).

**Experimental Design**

Two separate designs were utilized in this project. The primary consideration in the construction of these designs was that a more traditional, more conservative approach be employed than was utilized in Study I. It was desired that an increase in the quantity and frequency of observations of performance be accomplished in order to provide more stability in the estimation of the relevant system and environmental effects.

The first design, a mixed effects $3^3$ randomized block factorial (Kirk, 1968) included three independent variables each having three levels. The independent variables were: (a) Platform Motion, (b) G-Seat, (c) Field-of-View. Blocking was accomplished upon subjects in order that individual differences could be isolated. Twenty-seven unique treatment combinations were generated by the independent variables. This design was utilized in the investigation of three of the maneuvers studied: the aileron roll, the barrel roll, and the loop.

The second design was an extension of the first design and was used in the investigation of the remaining two maneuvers, the GCA and the 360° overhead pattern. A fourth independent variable, ceiling/visibility (C/V), with two levels was included. The inclusion of this additional variable increased the number of unique treatment combinations to 54. Thus, the second design was a mixed effects $3^3 2^1$ randomized block factorial. Blocking was again performed upon the subject variable in order that estimation of individual differences could be made. The same five subjects took part in both designs of the study. The order of treatment condition presentation was independently and stochastically randomized for each subject within the two designs.

The error terms for both designs were constructed assuming an additive model. That is, all block by treatment interactions were assumed to be zero. Thus, the error term was a linear combination of residual

block by treatment variances. This assumption was made because the subjects who were selected to participate in the study were highly qualified instructor pilots, and, therefore, it was inferred that the effects of learning the tasks would be minimized. Additionally, the treatment conditions were presented in a random fashion thus distributing any minimal learning effects equally between all specific treatments.

**Independent Variables**

The independent variables selected for study and investigated within the first design ($3^3$) were: Platform Motion, G-Seat, and Field-of-View.

Three levels of platform motion were selected. Those levels were: (a) no motion; (b) 3 DOF motion including movement in roll, pitch, and heave, (c) 6 DOF motion including roll, pitch, yaw, heave, lateral and longitudinal displacements.

The three levels of the G-seat variable included: (a) nonoperational; (b) seat pan bellows operational, backrest and thigh panel bellows nonoperational; and (c) fully operational.

The FOV variable also possessed three levels: (a) 300° horizontal (H) by 150° vertical (V) (full capability of ASPT); (b) 144° H x 36° V; and (c) 48° H x 36° V, representative of many single-channel visual displays.

The fourth variable investigated in this research was ceiling/visibility. This variable was included in part due to the interactive potential with the other independent variables which this factor demonstrated in Study 1 of this series of investigations. Another reason for the inclusion of this variable was that it provided a measuring stick, at least on the basis of face validity, of the reasonability of the effects which occurred and the measurements which were employed. If performance decreased under adverse weather conditions, as was expected, then more confidence in the direction of the effects of the simulator configuration variables would be warranted. The ceiling/visibility variable had two levels: (a) clear visibility and unlimited ceiling, and (b) minimum visibility and a specified ceiling altitude. The minimum ceiling/visibility condition was task specific, dependent upon the nature of the maneuver. For the 360° overhead pattern, the minimum ceiling was set at 1,200 feet above ground level (AGL) and the corresponding visibility was established at 3 miles (1,200 ft/three miles). The minimum condition for the GCA was set at 100 feet AGL/.25 mile. The minima for both maneuvers were established to represent real-world limitations.

The final factor investigated was subject (block) effects. This factor permitted investigation of anticipated individual differences by statistically isolating that portion of the total experimental variance due to subject differences.

**Dependent Variables**

A large number of dependent measures were collected in this study by way of the Automated Performance Measurement System (APMS) feature of ASPT. A complete listing of the measures collected in this study across all of the maneuvers is provided in Table 1. The measures generally fit into one of three basic categories: (a) system output measures; (b) pilot input measures; and (c) derived scores.

The system output measures reflect deviations using the root mean square technique from specified parameter criteria within particular segments of a maneuver. As such, smaller scores reflect smaller deviations and, hence, better performances. Maneuver segments were defined as non-overlapping portions of maneuvers wherein one or more desired parameter values were stabilized. Specific maneuver segments for each of the maneuvers investigated are illustrated in Appendix A.

The pilot input measures, or smoothness measures, represent an attempt to measure analogs of pilot workload. These measures are normally expressed in the form of elevator, aileron and rudder power for particular maneuver segments. An assumption made in judging the direction of this type of score was that smaller scores reflect less effort expended in controlling the simulator and therefore were more desirable.

The derived scores were composite scores for a segment or combination of segments within a maneuver. These scores were indications of how well the pilot remained within the tolerance limits of

*Table 1.* **Dependent Measure Listings for All Maneuvers**

| Variable | Units |
|---|---|
| **Aileron Roll** | |
| 1. Entry pitch | Degrees |
| 2. An average score of bank in, bank out and roll | Percent |
| 3. Entry and exit pitch score | Percent |
| 4. RMS bank in deviation | Degrees |
| 5. RMS bank out deviation | Degrees |
| 6. Elevator power during bank in | (Lbs-Deg)/Sec |
| 7. Aileron power during bank in | (Lbs-Deg)/Sec |
| 8. RMS pitch rate deviation during bank in | Deg/Sec |
| 9. RMS roll rate deviation during bank in | Deg/Sec |
| 10. RMS roll acceleration deviation during bank in | $Deg/Sec^2$ |
| 11. Elevator power during roll | (Lbs-Deg)/Sec |
| 12. Aileron power during roll | (Lbs-Deg)/Sec |
| 13. RMS pitch rate deviation during roll | Deg/Sec |
| 14. RMS roll rate deviation during roll | Deg/Sec |
| 15. Elevator power during bank out | (Lbs-Deg)/Sec |
| 16. Aileron power during bank out | (Lbs-Deg)/Sec |
| 17. RMS pitch rate deviation during bank out | Deg/Sec |
| 18. RMS roll rate deviation during bank out | Deg/Sec |
| **Barrel Roll** | |
| 1. Elevator power | (Lbs-Deg)/Sec |
| 2. Aileron power | (Lbs-Deg)/Sec |
| 3. Rudder power | (Lbs-Deg)/Sec |
| 4. RMS pitch rate deviation | Deg/Sec |
| 5. RMS roll rate deviation | Deg/Sec |
| 6. Total Score | Percent |
| 7. RMS pitch error-top half | Degrees |
| 8. RMS pitch error-bottom half | Degrees |
| **Loop** | |
| 1. Elevator power | (Lbs-Deg)/Sec |
| 2. Aileron power | (Lbs-Deg)/Sec |
| 3. RMS pitch rate deviation | Deg/Sec |
| 4. RMS roll rate deviation | Deg/Sec |
| 5. Total score | Percent |
| 6. RMS groundtrack deviation | Feet |
| 7. RMS pitch deviation | Degrees |
| **360° Overhead Pattern** | |
| 1. RMS vertical velocity deviation during pitchout | Feet/Sec |
| 2. RMS pitchout bank deviation | Degrees |
| 3. RMS pitchout altitude deviation | Feet |
| 4. Pitchout elevator power | (Lbs-Deg)/Sec |
| 5. Pitchout aileron power | (Lbs-Deg)/Sec |
| 6. RMS pitch rate deviation during pitchout | Deg/Sec |
| 7. RMS roll rate deviation during pitchout | Deg/Sec |
| 8. RMS vertical velocity during downwind | Ft/Min |
| 9. RMS downwind altitude deviation | Feet |
| 10. Downwind elevator power | (Lbs-Deg)/Sec |
| 11. Downwind aileron power | (Lbs-Deg)/Sec |

Table 1 (*Continued*)

| Variable | Units |
|---|---|
| 12. RMS downwind pitch rate deviation | Deg/Sec |
| 13. RMS downwind roll rate deviation | Deg/Sec |
| 14. RMS final turn bank deviation | Degrees |
| 15. RMS final turn airspeed deviation | Knots |
| 16. Final turn elevator power | (Lbs-Deg)/Sec |
| 17. Final turn aileron power | (Lbs-Deg)/Sec |
| 18. RMS final turn pitch rate deviation | Deg/Sec |
| 19. RMS final turn roll rate deviation | Deg/Sec |
| 20. RMS final approach glidepath deviation | Degrees |
| 21. RMS final approach course deviation | Feet |
| 22. RMS final approach airspeed deviation | Knots |
| 23. Landing X position | Feet |
| 24. Landing Y position | Feet |
| 25. Landing airspeed | Knots |
| 26. Landing heading | Degrees |
| 27. Landing vertical velocity | Ft/Min |
| 28. Elevator power final through landing | (Lbs-Deg)/Sec |
| 29. Aileron power final through landing | (Lbs-Deg)/Sec |
| 30. Rudder power final through landing | (Lbs-Deg)/Sec |
| 31. RMS pitch rate final through landing | Deg/Sec |
| 32. RMS roll rate final through landing | Deg/Sec |
| 33. RMS vertical velocity final through landing | Ft/Sec |
| 34. Overall pitch score | Percent |
| 35. Overall downwind score | Percent |
| 36. Overall final approach score | Percent |
| 37. Overall landing score | Percent |
| **Ground Controlled Approach (GCA)** | |
| 1. Total score | Percent |
| 2. Touchdown airspeed | Knots |
| 3. Touchdown heading | Degrees |
| 4. Touchdown vertical velocity | Ft/Sec |
| 5. RMS altitude deviation | Feet |
| 6. RMS airspeed deviation | Knots |
| 7. RMS centerline deviation | Feet |
| 8. RMS glidepath deviation | Degrees |
| 9. Elevator power prior to glideslope interception | (Lbs-Deg)/Sec |
| 10. Aileron power prior to glideslope | (Lbs-Deg)/Sec |
| 11. RMS pitch rate deviation prior to glideslope | Deg/Sec |
| 12. RMS roll rate deviation prior to glideslope | Deg/Sec |
| 13. Elevator power on glideslope | (Lbs-deg)/Sec |
| 14. Aileron power on glideslope | (Lbs-Deg)/Sec |
| 15. Rudder power on glideslope | (Lbs-Deg)/Sec |
| 16. RMS pitch rate deviation on glideslope | Deg/Sec |
| 17. RMS roll rate deviation on glideslope | Deg/Sec |

**Note.** — Lbs = pounds.
Deg = degrees.
Sec = second.
Ft = feet.
Min = minute.

several criteria simultaneously. These measurements were normally expressed as time-in-tolerance percentages with larger values representing better performances.

For a more comprehensive discourse on the specific derivations of these measures, consult Waag, Eddowes, Fuller, and Fuller (1975).

Although the number of dependent variables investigated in this study is relatively large, it still represents only a fraction of the measures which were available in the APMS system. The inclusion or exclusion of the available measures in this experiment was based upon the recommendations of expert pilots. Only those variables which were considered meaningful, reasonable indications of pilot performance for the particular maneuver under investigation were included.

**Maneuvers**

Five contact and instrument maneuvers were selected for the purpose of this study: aileron roll, barrel roll, loop, ground controlled approach and 360° overhead pattern. The aileron roll, GCA, and overhead pattern were chosen because they were included in Study I, and these maneuvers were investigated again to determine the constancy and generalizability of the earlier findings through testing with another sample of the subject population. The barrel roll and loop were included in this study to extend the analysis into the domain of higher G-force maneuvers. A complete discussion of the beginning and end points and scoring sequences of each of the maneuvers is included as Appendix A.

**Procedures**

Prior to data collection, each of the five subjects was provided approximately 4 hours of familiarization with the simulator (and safety factors) and familiarization with the types of simulator design configurations which would be investigated. This was accomplished by initially having the subjects fly the simulator in its normal full capability configuration. Next, the subjects were requested to complete several study maneuvers under a broad range of randomly selected independent variable conditions (e.g., motion, no motion, etc.). This training was constant for all subject pilots.

The data collection procedure was begun by having the pilot strap into the cockpit of the simulator and then having the console operator enter identification and system configuration information into the computer. The simulator was then initialized to one of five randomly selected maneuvers. The pilot was briefed on the task to be completed and all pertinent simulated weather conditions. After completion of this task, another randomly selected maneuver was initialized and the pilot was given the necessary instructions. This process was repeated a total of seven times per mission. The subjects normally flew two to three missions per session lasting approximately 2 hours, with rest periods provided whenever requested. All sorties were flown in cockpit B of the simulator in an attempt to control for possible inter-cockpit differences. In accomplishing the ground controlled approach, all verbal, glideslope, glidepath and distance information was conveyed via the Cognitronics voice generator. All measurements were stored on magnetic disk for subsequent analysis.

**Analysis**

Multivariate analyses of variance (MANOVA) were performed on each of the five maneuvers. The multivariate analyses were selected as the appropriate omnibus test due to the intercorrelation and interdependencies of the measurement sets. The significance criterion was established at the .05 probability level for all multivariate and univariate tests. Following the MANOVA, in those cases where significant multivariate F's were obtained, traditional stepdown univariate F's were computed in order to ascertain the location of the significance within the measurement set (Harris, 1975). Once the specific variable(s) was found, Tukey's tests were performed to determine the direction of the effect. This analytic procedure was followed for both designs. Finally, an index of the strength of the univariate effects was calculated for each dependent measure where multivariate and univariate significance was obtained. This index was calculated using the ratio of the sums of squares for an effect over the total nonerror sums of squares. This index represents a proportionate reduction in the total nonerror variability due to each specific effect and thus provides a relative measurement of the importance of an effect.

## III. RESULTS OF STUDY II

Significant multivariate and univariate effects were discovered in all flight maneuvers. Inspection of Table 2 reveals those specific independent variables producing significant multivariate effects for all of the maneuvers investigated.

*Table 2.* **Significant Multivariate Effects Across All Maneuvers in Both Designs of Study II**

| Effect | Aileron Roll | Barrel Roll | Loop | GCA | Overhead Pattern |
|---|---|---|---|---|---|
| A(FOV) | .047 | .000 | N/S | .039 | .000 |
| B(Motion) | N/S | .096 | .027 | .023 | .000 |
| C(G-seat) | N/S | N/S | N/S | N/S | N/S |
| D(C/V) | – | – | – | .000 | .000 |
| S(Block) | .000 | .000 | .000 | .000 | .000 |
| AB(FOVxMOT) | N/S | N/S | .071 | N/S | N/S |
| AC | N/S | N/S | N/S | N/S | N/S |
| BC | N/S | N/S | N/S | N/S | N/S |
| AD | – | – | – | N/S | N/S |
| BD(MOTxC/V) | – | – | – | .026 | N/S |
| CD | – | – | – | N/S | N/S |
| ABC | N/S | N/S | N/S | N/S | N/S |
| ABD | – | – | – | N/S | N/S |
| ACD | – | – | – | N/S | N/S |
| BCD | – | – | – | N/S | N/S |
| ABCD | – | – | – | N/S | N/S |

**Note.** — Table entries are probability levels.
N/S = Not Significant.
– = Not Estimated.
FOV = Field-of-View.
C/V = Ceiling/Visibility.
MOT = Motion.

*Field-of-View (FOV).* The first system variable investigated, field-of-view, produced significant multivariate effects in four of the five maneuvers: the aileron roll, barrel roll, GCA and 360° overhead pattern. Table 3 depicts the univariate analysis of variance and the cell means within each maneuvers's measurement set showing those specific dependent variables which contributed toward the overall multivariate significance. In the aileron roll maneuver, three of the 18 total variables collected showed significant field-of-view main effects. In this maneuver, best performance was demonstrated under the full field-of-view condition for the average bank in, out and roll score but under the most restricted FOV conditions for the other measures: elevator power and RMS pitch rate during roll.

In the barrel roll maneuver, four of the eight total measures showed univariate significance ($p < .05$) due to the FOV variable. The general trend in these measures was that superior performance accompanied either the large or the medium FOV levels, and worst performance was normally associated with the most restricted FOV condition. This was true in three of the four measures: aileron power, RMS roll rate and RMS pitch error during the bottom half of the maneuver. The fourth maneuver, elevator power during roll, demonstrated best performance under the most restricted FOV condition and worst performance in the medium FOV setting.

In the overhead pattern maneuver, 12 of the 37 total measures collected demonstrated significant ($p < .05$) FOV main effects with 9 of these showing best performance under the two larger FOV

*Table 3.* **Univariate Field-of-View Main Effects and Means Across Maneuvers**

| Source | $\bar{X}$(Full) | $\bar{X}$(Med) | $\bar{X}$(Small) | SSB | SSW | F | P |
|---|---|---|---|---|---|---|---|
| **Aileron Roll** | | | | | | | |
| 1 Entry pitch | 29.386 | 29.383 | 28.452 | 26.09 | 477.47 | 2.841 | .062 |
| 2 Average score on bank in, out and roll | 85.847* | 84.320 | 79.305* | 1,054.350 | 13,834.169 | 3.963 | .021* |
| 3. Entry and exit pitch score | −4.734 | −4.780 | −5.706 | 27.049 | 822.93 | 1.709 | .186 |
| 4. RMS bank in deviation | 1.107 | 1.092 | 1.287 | 1.061 | 36.49 | 1.513 | .225 |
| 5. RMS bank out deviation | 2.276 | 2.928 | 3.427 | 29.993 | 555.94 | 2.805 | .065 |
| 6. Elevator power during bank-in | 3.465 | 2.771 | 2.887 | 12.457 | 290.69 | 2.228 | .112 |
| 7. Aileron power during bank-in | .212 | .135 | .182 | .135 | 3.283 | 2.14 | .122 |
| 8. RMS pitch rate deviation during bank in | 6.418 | 6.030 | 6.109 | 3.791 | 168.10 | 1.172 | .313 |
| 9. RMS roll rate deviation during bank in | 1.073 | .841 | 1.056 | 1.509 | 48.423 | 1.621 | .202 |
| 10. RMS roll acceleration deviation during bank in | 3.289 | 2.307 | 3.225 | 27.155 | 814.75 | 1.733 | .181 |
| 11. Elevator power during roll | 1.191 | 1.465* | .887* | 7.527 | 61.996 | 6.313 | .002* |
| 12. Aileron power during roll | 5.026 | 4.467 | 4.500 | 8.833 | 980.33 | .468 | .627 |
| 13. RMS pitch rate during roll | 4.333 | 4.823* | 4.268* | 8.382 | 118.210 | 3.663 | .029* |
| 14. RMS roll rate deviation during roll | 49.519 | 47.934 | 49.367 | 68.846 | 4,763.36 | .751 | .474 |
| 15. Elevator power during bank-out | 5.139 | 6.850 | 5.593 | 70.773 | 5,371.09 | .685 | .506 |
| 16. Aileron power during bank-out | 2.346 | 3.417 | 4.114 | 71.334 | 2,352.12 | 1.577 | .211 |
| 17. RMS pitch rate deviation during bank-out | 1.518 | 2.021 | 1.814 | 5.758 | 143.12 | 2.092 | .128 |
| 18. RMS roll rate deviation during bank-out | 5.126 | 5.459 | 6.542 | 49.333 | 2,991.27 | .857 | .427 |
| All F-ratios calculated with $df_{2,104}$ | | | | | | | |
| **Barrel Roll** | | | | | | | |
| 1. Elevator power during roll | 3.474 | 4.144* | 3.111* | 24.754 | 260.365 | 4.994 | .008* |
| 2. Aileron power | 1.191 | 1.181* | 1.564* | 4.289 | 53.085 | 4.201 | .170 |
| 3. Rudder power | .377 | .307 | .343 | .110 | 15.050 | .380 | .684 |
| 4. RMS pitch rate deviation | 9.688 | 10.053 | 9.310 | 12.409 | 410.954 | 1.570 | .212 |
| 5. RMS roll rate | 18.023 | 17.532* | 21.606* | 445.334 | 2,098.737 | 11.034 | .000* |
| 6. Total score | 66.986 | 58.770 | 60.487 | 1,690.40 | 30,649.79 | 2.867 | .061 |
| 7. RMS pitch error-top half | 9.591 | 10.602 | 9.993 | 23.297 | 1,210.15 | 1.001 | .371 |
| 8. RMS pitch error during bottom half | 10.026* | 11.457 | 12.984* | 197.706 | 2,221.710 | 4.627 | .011* |
| All F-ratios calculated with $df_{2,104}$ | | | | | | | |

Table 3 (*Continued*)

| Source | $\bar{X}$(Full) | $\bar{X}$(Med) | $\bar{X}$(Small) | SSB | SSW | F | P |
|---|---|---|---|---|---|---|---|
| **Overhead Pattern** | | | | | | | |
| 1. RMS vertical velocity deviation during pitchout | 262.199 | 263.954 | 254.570 | 4,583.03 | 3,011.576 | .161 | .851 |
| 2. RMS pitchout bank deviation | 4.145* | 3.298 | 3.324* | 41.813 | 578.740 | 8.544 | .000* |
| 3. RMS pitchout altitude deviation | 39.652 | 38.103 | 38.897 | 108.024 | 102,562.5 | .116 | .894 |
| 4. Pitchout elevator power | 2.131 | 2.193 | 2.179 | .185 | 218.742 | .089 | .914 |
| 5. Pitchout aileron power | 1.201 | 1.229 | 1.282 | .307 | 100.205 | .325 | .722 |
| 6. RMS pitch rate deviation during pitchout | 6.963 | 7.187 | 7.219 | 3.511 | 140.393 | 2.651 | .072 |
| 7. RMS roll rate pitchout | 7.740 | 7.979* | 8.340* | 16.420 | 501.958 | 3.467 | .033* |
| 8. RMS vertical velocity during downwind | 230.977 | 253.082 | 246.492 | 23,183.7 | 2,111,276. | 1.164 | .314 |
| 9. RMS downwind altitude | 35.505 | 37.628 | 35.267 | 304.091 | 88,049.6 | .366 | .693 |
| 10. Downwind elevator power | 1.076 | 1.159 | 1.227 | 1.032 | 63.444 | 1.725 | .180 |
| 11. Downwind aileron power | .651 | .641 | .709 | .242 | 32.705 | .785 | .457 |
| 12. RMS downwind pitch rate deviation | 1.148 | 1.167 | 1.122 | .091 | 19.240 | .505 | .603 |
| 13. RMS downwind roll rate deviation | 2.965 | 2.920 | 3.154 | 2.759 | 303.24 | .964 | .382 |
| 14. RMS final turn bank deviation | 6.404* | 7.921 | 9.015* | 309.530 | 1,971.813 | 16.639 | .000* |
| 15. RMS final turn airspeed deviation | 3.438 | 3.827 | 4.099 | 19.876 | 798.587 | 2.638 | .073 |
| 16. Elevator power final turn | .966* | .956 | .806* | 1.444 | 49.965 | 3.064 | .048* |
| 17. Aileron power final turn | .863* | .759 | .732* | .859 | 28.049 | 3.247 | .040* |
| 18. RMS pitch rate final turn | 2.718* | 2.874* | 2.662 | 2.181 | 36.239 | 6.381 | .002* |
| 19. RMS final turn roll rate deviation | 3.650 | 3.548 | 3.608 | .478 | 200.076 | .253 | .776 |
| 20. RMS final approach glidepath deviation | 1.246 | 1.196 | 1.382 | 1.667 | 81.655 | 2.164 | .117 |
| 21. RMS final approach course deviation | 23.554* | 53.936 | 90.702* | 203,506.14 | 422.977 | 15.035 | .000* |
| 22. Final approach airspeed RMS deviation | 3.815* | 3.815* | 5.366* | 134.58 | 2,498.08 | 5.710 | .003* |
| 23. Landing X position | 7.988 | 9.923 | 9.591 | 192.770 | 9,712.18 | 2.103 | .124 |
| 24. Landing Y position | −708.840 | −736.079 | −780.244 | 233,730. | 15,617,740. | 1.586 | .207 |
| 25. Landing airspeed | 79.497 | 78.875 | 79.890 | 47.176 | 3,674.43 | 1.361 | .258 |
| 26. Landing heading | 301.780 | 301.946 | 301.690 | 3.029 | 171.483 | 1.872 | .150 |
| 27. Landing vertical velocity | −273.65 | −254.029 | −269.970 | 19,580.4 | 1,596,654. | 1.299 | .274 |
| 28. Elevator power final through landing | 2.398 | 2.380 | 2.472 | .427 | 235.690 | .192 | .825 |
| 29. Aileron power final through landing | .903* | 1.130 | 1.261* | 5.936 | 63.653 | 9.885 | .000* |
| 30. Rudder power final through landing | .379* | .420 | .505* | .739 | 19.751 | 3.967 | .020* |
| 31. RMS pitch rate final through landing | 1.938* | 1.312 | 1.409* | 6.599 | 46.897 | 14.917 | .000* |
| 32. RMS roll rate final through landing | 2.913* | 3.661* | 4.119 | 66.711 | 461.564 | 15.320 | .000* |
| 33. RMS vertical velocity final through landing | 16.348 | 16.523 | 15.890 | 19.204 | 2,318.06 | .878 | .417 |

Table 3 (*Continued*)

| Source | $\overline{X}$(Full) | $\overline{X}$(Med) | $\overline{X}$(Small) | SSB | SSW | F | P |
|---|---|---|---|---|---|---|---|
| 34. Overall pitch score | 63.890 | 67.423 | 66.594 | 614.36 | 195,232. | .333 | .716 |
| 35. Overall downwind score | 66.401 | 63.326 | 59.737 | 2,002.69 | 98,451.0 | 2.156 | .118 |
| 36. Overall final approach score | 17.329 | 19.478 | 14.028 | 1,356.68 | 86,661.4 | 1.659 | .192 |
| 37. Overall landing | 81.334 | 81.736 | 80.166 | 119.613 | 11,904.77 | 1.065 | .346 |
| All F-ratios calculated with $df_{2,212}$ | | | | | | | |
| **Ground Controlled Approach** | | | | | | | |
| 1. Total score | 57.675 | 58.771 | 59.36 | 131.897 | 51,010.27 | .268 | .764 |
| 2. Touchdown airspeed | 74.208 | 74.486 | 76.030 | 173.386 | 8,103.242 | 2.268 | .106 |
| 3. Touchdown heading | 301.521 | 301.580 | 301.533 | .179 | 177.642 | .107 | .898 |
| 4. Touchdown vertical velocity | −154.916 | −153.615 | −173.771 | 22,903.13 | 1,379,232.5 | 1.760 | .174 |
| 5. RMS altitude deviation | 24.246 | 23.500 | 24.305 | 36.255 | 23,342.57 | .164 | .848 |
| 6. RMS airspeed deviation | 1.760 | 1.737 | 1.668 | .416 | 68.587 | .644 | .526 |
| 7. RMS centerline deviation | 61.679 | 63.093 | 59.309 | 657.912 | 104,070.05 | .670 | .512 |
| 8. RMS glidepath deviation | 24.482 | 25.274 | 24.438 | 39.808 | 13,072.49 | .322 | .724 |
| 9. Elevator power prior to glideslope | .345 | .290 | .300 | .155 | 9.298 | 1.772 | .172 |
| 10. Aileron power prior to glideslope | .373 | .353 | .381 | .036 | 6.598 | .582 | .559 |
| 11. RMS pitch rate deviation prior to glideslope | .626 | .604 | .611 | .022 | 6.143 | .389 | .678 |
| 12. RMS roll rate deviation prior to glideslope | 1.763 | 1.739 | 1.941 | 2.186 | 80.185 | 2.890 | .057 |
| 13. Elevator power on glideslope | 4.459 | 4.343 | 3.955 | 12.571 | 1,114.639 | 1.195 | .304 |
| 14. Aileron power on glideslope | .851 | .791 | .831 | .165 | 94.535 | .186 | .830 |
| 15. Rudder power on glideslope | 1.073 | 1.048 | 1.133 | .338 | 122.55 | .293 | .746 |
| 16. RMS pitch rate deviation | 1.201 | 1.222 | 1.164 | .151 | 13.101 | 1.226 | .295 |
| 17. RMS roll rate on glideslope | 2.013 | 1.981* | 2.359* | 7.919 | 245.29 | 3.422 | .034* |
| All F-ratios calculated with $df_{2,212}$ | | | | | | | |

*Indicates significant ($p < .05$) difference found.

conditions. Furthermore, 7 of these 12 measures also showed worst performance under the most restricted FOV condition. Those significant measures demonstrating worst performance in other than the most restricted display condition were: elevator, aileron power and RMS pitch rate in the final turn, and RMS pitch rate in the final through landing segments.

Multivariate significance was also demonstrated for the FOV variable in the GCA maneuver. In this maneuver, however, only one of the 17 dependent variables (RMS roll rate on the glideslope) showed a significant univariate effect. In this measure, best performance was demonstrated in the medium FOV setting followed by somewhat poorer performance under the maximum FOV condition and worst performance in the smallest FOV condition.

*Motion*. Significant multivariate motion effects were demonstrated in three of the five maneuvers investigated in this study: the loop, overhead pattern and GCA. Additionally, the motion effects

approximated significance ($p < .096$) on another maneuver, the barrel roll. Table 4 illustrates the univariate analyses and means for the dependent measures in the three maneuvers.

*Table 4.* **Univariate Motion Main Effects and Means Across Maneuvers**

| Source | $\bar{X}$(Off) | $\bar{X}$(3 DOF) | $\bar{X}$(6 DOF) | SSB | SSW | F | P |
|---|---|---|---|---|---|---|---|
| **Loop** | | | | | | | |
| 1. Elevator power | 5.107 | 5.556 | 5.829 | 11.979 | 562.769 | 1.106 | .334 |
| 2. Aileron power | .346 | .394 | .458 | .285 | 15.393 | .965 | .384 |
| 3. RMS pitch rate deviation | 13.150 | 13.116 | 13.462 | 3.263 | 182.319 | .930 | .397 |
| 4. RMS roll rate deviation | 2.278 | 2.374 | 2.550 | 1.703 | 179.136 | .494 | .611 |
| 5. Total score | 41.292* | 52.857* | 54.880* | 1,282.415 | 48,352.65 | 1.379 | .007* |
| 6. RMS groundtrack deviation | 125.143 | 123.876 | 120.127 | 612.324 | 1,171,658.8 | .027 | .973 |
| 7. RMS pitch deviation | 3.310 | 3.165 | 3.011 | 2.011 | 74.087 | 1.411 | .248 |
| F-ratios calculated with $df_{2,104}$ | | | | | | | |
| **Overhead Pattern** | | | | | | | |
| 1. RMS vertical velocity deviation during pitchout | 261.191 | 269.743 | 249.689 | 18,228.16 | 3,011,576.9 | .641 | .527 |
| 2. RMS pitchout bank deviation | 3.870 | 3.600 | 3.297 | 14.776 | 518.740 | 3.019 | .050 |
| 3. RMS pitchout altitude deviation | 41.382 | 37.903 | 37.366 | 855.888 | 102,562.55 | .884 | .414 |
| 4. Pitchout elevator power | 2.047 | 2.197 | 2.260 | 2.158 | 218.742 | 1.045 | .353 |
| 5. Pitchout aileron power | 1.179 | 1.253 | 1.281 | .492 | 100.205 | .520 | .594 |
| 6. RMS pitch rate deviation during pitchout | 7.099 | 7.077 | 7.195 | .709 | 140.393 | .535 | .586 |
| 7. RMS roll rate deviation during pitchout | 8.125 | 7.982 | 7.952 | 1.547 | 501.958 | .326 | .721 |
| 8. RMS vertical velocity during downwind | 247.032 | 235.856 | 247.663 | 7,941.54 | 2,111,276.6 | .398 | .671 |
| 9. RMS downwind altitude deviation | 36.559 | 33.765 | 38.075 | 860.371 | 88,049.663 | 1.035 | .356 |
| 10. Downwind elevator power | .944* | 1.169 | 1.349* | 7.399 | 63.444 | 12.363 | .000* |
| 11. Downwind aileron power | .608 | .701 | .692 | .470 | 1.318 | 1.525 | .219 |
| 12. RMS downwind pitch rate | 1.085* | 1.128 | 1.224* | .918 | 19.240 | 5.062 | .007* |
| 13. RMS downwind roll rate deviation | 3.084 | 3.000 | 2.956 | .756 | 303.241 | .264 | .767 |
| 14. RMS final turn bank deviation | 7.668 | 7.908 | 7.764 | 2.623 | 1,971.813 | .141 | .868 |
| 15. RMS final turn airspeed deviation | 3.837 | 4.012 | 3.514 | 11.490 | 798.587 | 1.525 | .220 |
| 16. Final turn elevator power | .772* | .903 | 1.053* | 1.444 | 49.965 | 7.522 | .000* |
| 17. Final turn aileron power | .614* | .837* | .902 | .859 | 28.049 | 15.325 | .000* |
| 18. RMS final turn pitch rate deviation | 2.709 | 2.739 | 2.807 | .453 | 36.239 | 1.326 | .267 |
| 19. RMS final turn roll rate deviation | 3.435 | 3.666 | 3.705 | 3.843 | 200.076 | 2.036 | .133 |
| 20. RMS final approach glidepath deviation | 1.325 | 1.182 | 1.318 | 1.157 | 81.655 | 1.502 | .225 |
| 21. RMS final approach course deviation | 65.796 | 54.595 | 47.801 | 14,863.35 | 1,434,750.7 | 1.098 | .335 |
| 22. RMS final approach airspeed deviation | 4.254 | 4.563 | 4.294 | 5.074 | 2,498.084 | .215 | .800 |
| 23. Landing X position | 8.045 | 9.273 | 10.183 | 207.222 | 9,712.184 | 2.261 | .106 |
| 24. Landing Y position | −733.852 | −725.221 | −766.090 | 83,523.27 | 15,617,740. | .566 | .568 |
| 25. Landing airspeed | 79.651 | 79.479 | 79.132 | 12.590 | 3,674.431 | .363 | .695 |
| 26. Landing heading | 301.584* | 302.032* | 301.800 | 3.029 | 171.483 | 5.576 | .004* |
| 27. Landing vertical | −267.283 | −269.269 | −261.097 | 3,269.967 | 1,596,654.4 | .217 | .805 |
| 28. Final through landing elevator power | 2.091* | 2.528 | 2.631* | .427 | 235.690 | 6.656 | .001* |

Table 4 (*Continued*)

| Source | $\bar{X}$(Off) | $\bar{X}$(3 DOF) | $\bar{X}$(6 DOF) | SSB | SSW | F | P |
|---|---|---|---|---|---|---|---|
| 29. Aileron power final through landing | 1.032 | 1.187 | 1.075 | 1.159 | 63.653 | 1.930 | .147 |
| 30. Rudder power final through landing | .393 | .454 | .457 | .238 | 19.751 | 1.278 | .280 |
| 31. RMS pitch rate final through landing | 1.238 | 1.264 | 1.264 | .034 | 46.897 | .077 | .925 |
| 32. RMS roll rate final through landing | 3.794 | 3.564 | 3.335 | 9.482 | 461.564 | 2.177 | .115 |
| 33. RMS vertical velocity final through landing | 116.170 | 16.331 | 16.260 | 1.166 | 2,318.062 | .053 | .948 |
| 34. Overall pitch score | 62.205 | 69.222 | 66.479 | 2,251.185 | 195,232.78 | 1.222 | .296 |
| 35. Overall downwind score | 61.356 | 65.590 | 62.517 | 861.623 | 98,451.057 | .927 | .397 |
| 36. Overall final approach score | 18.024 | 18.061 | 14.794 | 650.844 | 86,661.405 | .796 | .452 |
| 37. Overall landing score | 80.075 | 81.322 | 81.838 | 147.884 | 11,904.779 | 1.316 | .270 |
| All F-ratios calculated with $df_{2,212}$ | | | | | | | |
| **Ground Controlled Approach** | | | | | | | |
| 1. Total score | 60.763 | 55.840 | 59.205 | 1,139.474 | 52,010.277 | 2.322 | .100 |
| 2. Touchdown airspeed | 74.326 | 75.317 | 75.080 | 48.201 | 8,103.242 | .630 | .533 |
| 3. Touchdown heading | 301.575 | 301.575 | 301.484 | .501 | 177.642 | .299 | .741 |
| 4. Touchdown vertical velocity | –156.466 | –169.122 | –156.71 | 9,424.665 | 1,379,232.5 | .724 | .485 |
| 5. RMS altitude deviation | 23.196 | 25.317 | 23.538 | 233.334 | 23,342.570 | 1.059 | .348 |
| 6. RMS airspeed deviation | 1.703 | 1.784 | 1.678 | .555 | 68.587 | .858 | .425 |
| 7. RMS centerline | 59.53 | 66.55* | 57.98* | 3,756.283 | 104,070.05 | 3.825 | .023* |
| 8. RMS glidepath deviation | 24.730 | 24.406 | 25.058 | 19.079 | 13,072.493 | .154 | .856 |
| 9. Elevator power prior to glideslope | .26* | .32 | .34* | .155 | 9.298 | 3.484 | .032* |
| 10. Aileron power prior to glideslope | .31* | .40* | .38 | .443 | 6.598 | 7.128 | .001* |
| 11. RMS pitch rate prior to glideslope | .57* | .62 | .63* | .198 | 80.185 | 3.433 | .034* |
| 12. RMS roll rate prior to glideslope | 1.67* | 1.90* | 1.86 | 2.597 | 80.185 | 3.433 | .034* |
| 13. Elevator power on to glideslope | 4.317 | 4.496 | 3.944 | 14.262 | 1,114.639 | 1.356 | .259 |
| 14. Aileron power on glideslope | .61* | .96* | .89 | 6.144 | 94.535 | 6.889 | .001* |
| 15. Rudder power on glideslope | 1.000 | 1.175 | 1.079 | 1.379 | 122.555 | 1.193 | .305 |
| 16. RMS pitch rate deviation on glideslope | 1.180 | 1.217 | 1.190 | .065 | 13.101 | .531 | .588 |
| 17. RMS roll rate on glideslope | 1.78* | 2.28* | 2.27 | 14.749 | 245.290 | 6.373 | .002* |
| All F-ratios calculated with $df_{2,212}$ | | | | | | | |

*Indicates significance ($p < .05$).

In the loop, only one of seven total measures, total score, registered significance due to the motion variable. In this case, best performance was demonstrated under full 6 DOF with somewhat poorer performance under 3 DOF motion and worst performance under the no-motion condition. This was the only univariate case in the study where best performance was demonstrated with the full motion condition.

Six dependent measures in the overhead pattern maneuver showed significant effects due to the platform motion variable. Five of these measures showed superior performance under the no-motion condition, and showed corresponding decrements in performance as DOFs were added to the platform motion's operation. The other measure, landing heading showed significant differences in another direction.

Motion main effects in the GCA were exhibited in Seven of the 17 total measures which were collected. Of these seven, six measures demonstrated best performance accompanied by the no-motion condition and poorer performance associated with some form of motion. Those measures were: elevator power, aileron power, RMS pitch rate, RMS roll rate prior to glideslope interception, and aileron power, RMS roll rate after glideslope interception.

*G-Seat*. The final system variable to be investigated, the G-seat, was conspicuous by the complete absence of significant multivariate effects in any of the maneuvers. This is the only occurrence in the study where a significant main effect did not surface.

*Ceiling/Visibility*. The only environmental variable evaluated in this study, ceiling/visibility, produced multivariate and univariate significance in the two maneuvers where it was manipulated. Table 5 presents the dependent variables in these two maneuvers, the overhead pattern and the GCA. Nineteen of the measures in the overhead pattern demonstrated a significant ceiling/visibility effect, all of which showed best performance with clear conditions. Similarly, in the GCA maneuver, 14 of the 17 measures collected showed significance on this variable, all with best performance demonstrated under the clear conditions.

*Table 5.* **Univariate Ceiling/Visibility Main Effects and Means Across Maneuvers**

| Source | $\bar{X}$ (Clear) | $\bar{X}$ (Min) | SSB | SSW | F | P |
|---|---|---|---|---|---|---|
| **Overhead Pattern** | | | | | | |
| 1. RMS vertical velocity deviation during pitchout | 264.397 | 256.018 | 4,739.539 | 3,011,576.9 | .333 | .564 |
| 2. RMS pitchout bank deviation | 3.677 | 3.501 | 2.095 | 518.740 | .856 | .355 |
| 3. RMS pitchout altitude deviation | 38.508 | 39.259 | 38.114 | 102,562.55 | .078 | .779 |
| 4. Pitchout elevator power | 2.012 | 2.323 | 6.559 | 218.742 | 6.357 | .012* |
| 5. Pitchout aileron power | 1.211 | 1.264 | .194 | 100.205 | .410 | .522 |
| 6. RMS pitch rate deviation during pitchout | 7.146 | 7.101 | .139 | 140.393 | .210 | .647 |
| 7. RMS roll rate deviation during pitchout | 7.995 | 8.044 | .165 | 501.958 | .069 | .792 |
| 8. RMS downwind vertical velocity | 209.324 | 277.710 | 315,668.38 | 2,111,276.6 | 31.697 | .000* |
| 9. RMS downwind altitude deviation | 30.614 | 41.652 | 8,223.804 | 88,049.663 | 19.800 | .000* |
| 10. Downwind elevator power | .959 | 1.349 | 10.290 | 63.444 | 34.385 | .000* |
| 11. Downwind aileron power | .538 | .796 | 4.503 | 32.705 | 29.194 | .000* |
| 12. RMS downwind pitch rate deviation | .925 | 1.367 | 13.168 | 19.240 | 145.090 | .000* |
| 13. RMS downwind roll rate deviation | 2.687 | 3.339 | 28.630 | 303.241 | 20.016 | .000* |
| 14. RMS final turn bank deviation | 7.362 | 8.198 | 47.245 | 1,971.81 | 5.079 | .025* |
| 15. RMS final turn airspeed deviation | 3.371 | 4.199 | 45.622 | 798.587 | 12.111 | .000* |
| 16. Final turn airspeed power | .793 | 1.025 | 3.642 | 49.965 | 15.453 | .000* |
| 17. Final turn aileron power | .695 | .874 | 2.150 | 28.049 | 16.257 | .000* |
| 18. RMS final turn pitch rate deviation | 2.681 | 2.822 | 1.338 | 36.239 | 7.831 | .005* |
| 19. RMS final turn roll rate deviation | 3.316 | 3.889 | 22.132 | 200.076 | 23.452 | .000* |
| 20. RMS final approach glidepath deviation | 1.223 | 1.326 | .719 | 81.655 | 1.868 | .173 |
| 21. RMS final approach course deviation | 54.373 | 57.755 | 772.027 | 1,434,750.7 | .114 | .735 |
| 22. RMS final approach airspeed deviation | 3.818 | 4.922 | 82.207 | 2,498.084 | 6.976 | .008* |

Table 5 (*Continued*)

| Source | $\bar{X}$ (Clear) | $\bar{X}$ (Min) | SSB | SSW | F | P |
|---|---|---|---|---|---|---|
| 23. Landing X position | 10.518 | 7.816 | 492.699 | 9,712.184 | 10.754 | .001* |
| 24. Landing Y position | –744.206 | –739.236 | 1,667.520 | 15,617,740. | .022 | .880 |
| 25. Landing airspeed | 79.119 | 79.723 | 24.607 | 3,674.431 | 1.419 | .234 |
| 26. Landing heading | 301.835 | 301.835 | .244 | 171.483 | .301 | .583 |
| 27. Landing vertical velocity | –263.609 | –268.157 | 1,396.057 | 1,596,654.4 | .185 | .667 |
| 28. Elevator power final through landing | 2.352 | 2.481 | 1.136 | 235.690 | 1.022 | .313 |
| 29. Aileron power final through landing | 1.02 | 1.17 | 1.639 | 63.653 | 5.462 | .020* |
| 30. Rudder power final through landing | .419 | .450 | .066 | 19.751 | .709 | .400 |
| 31. RMS pitch rate final through landing | 1.230 | 1.276 | .140 | 46.897 | .637 | .425 |
| 32. RMS roll rate final through landing | 3.395 | 3.735 | 7.794 | 461.564 | 3.579 | .059 |
| 33. RMS vertical velocity acceleration deviation final through landing | 15.814 | 16.694 | 52.307 | 2,318.062 | 4.783 | .029* |
| 34. Overall pitch score | 66.508 | 65.429 | 78.501 | 195,232.78 | .085 | .770 |
| 35. Overall downwind score | 70.069 | 56.240 | 12,908.604 | 98,451.057 | 27.796 | .000* |
| 36. Final approach score | 19.571 | 14.319 | 2,862.059 | 86,661.405 | 4.555 | .034* |
| All F-ratios calculated with $df_{1,212}$ | | | | | | |
| **Ground Controlled Approach** | | | | | | |
| 1. Total score | 62.975 | 54.230 | 5,162.095 | 52,010.27 | 21.041 | .000* |
| 2. Touchdown airspeed | 74.706 | 75.109 | 11.001 | 8,103.242 | .287 | .592 |
| 3. Touchdown heading | 301.667 | 301.422 | 4.059 | 177.642 | 4.845 | .028* |
| 4. Touchdown vertical velocity | –159.074 | –162.461 | 774.516 | 1,379,232.5 | .119 | .730 |
| 5. RMS altitude deviation | 22.125 | 25.909 | 966.550 | 23,342.570 | 8.778 | .003* |
| 6. RMS airspeed deviation | 1.534 | 1.909 | 9.497 | 68.587 | 29.357 | .000* |
| 7. RMS centerline deviation | 54.135 | 68.586 | 14,096.321 | 104,070.05 | 28.715 | .000* |
| 8. RMS glidepath deviation | 23.768 | 25.694 | 250.369 | 13,072.493 | 4.060 | .045* |
| 9. Elevator power prior to glideslope | .267 | .356 | .532 | 9.298 | 12.151 | .000* |
| 10. Aileron power prior to glideslope | .301 | .437 | 1.240 | 6.498 | 39.845 | .000* |
| 11. RMS pitch rate prior to glideslope | .521 | .707 | 2.351 | 6.143 | 81.148 | .000* |
| 12. RMS roll rate prior to glideslope | 1.389 | 2.240 | 48.806 | 80.185 | 129.039 | .000* |
| 13. Elevator power on glideslope | 3.945 | 4.559 | 25.419 | 1,114.639 | 4.834 | .029* |
| 14. Aileron power on glideslope | .553 | 1.096 | 19.870 | 94.535 | 44.560 | .000* |
| 15. Rudder power on glideslope | .794 | 1.375 | 22.748 | 122.553 | 39.351 | .000* |
| 16. RMS pitch rate deviation on glideslope | 1.175 | 1.216 | .114 | 13.101 | 1.852 | .175 |
| 17. RMS roll rate on glideslope | 1.523 | 2.713 | 95.580 | 245.290 | 82.607 | .000* |
| All F-ratios calculated with $df_{1,212}$ | | | | | | |

*Indicates significance ($p < .05$).

*Interactions*. Only one interaction reached the criterion for multivariate significance in any of the five maneuvers. One other interaction, the first order FOV by platform motion interaction in the loop approximated significance ($p < .07$), but did not exceed the selected criterion ($p < .05$). The interaction attaining a significant level was the first order platform motion by ceiling/visibility interaction in the GCA maneuver. Table 6 depicts the univariate analyses and cell means for all of the dependent measures in this maneuver.

*Table 6.* **Univariate Motion by Ceiling/Visibility Interactions in the Ground Controlled Approach**

| Source | $\bar{X}$ (Clear) | | | $\bar{X}$ (Minimums) | | | | |
|---|---|---|---|---|---|---|---|---|
| | $\bar{X}$(Off) | $\bar{X}$(3 DOF) | $\bar{X}$(6 DOF) | $\bar{X}$(Off) | $\bar{X}$(3 DOF) | $\bar{X}$(6 DOF) | F | P |
| 1. Total score | 62.804 | 62.277 | 63.844 | 58.722 | 49.403 | 54.566 | 1.792 | .169 |
| 2. Touchdown airspeed | 74.259 | 74.498 | 75.360 | 74.393 | 76.135 | 74.800 | .742 | .477 |
| 3. Touchdown heading | 301.15 | 301.722 | 301.565 | 301.435 | 301.428 | 301.403 | .141 | .868 |
| 4. Touchdown vertical velocity | −155.782 | −155.839 | −165.600 | −157.151 | −182.404 | −147.832 | 1.710 | .183 |
| 5. RMS altitude deviation | 21.768 | 23.070 | 21.537 | 24.625 | 27.564 | 25.538 | .143 | .866 |
| 6. RMS airspeed deviation | 1.522 | 2.581 | 1.500 | 1.885 | 1.987 | 1.856 | .048 | .952 |
| 7. RMS centerline deviation | 53.160 | 56.314 | 52.930 | 65.904 | 76.805 | 63.048 | 1.333 | .265 |
| 8. RMS glidepath deviation | 25.347 | 23.497 | 22.461 | 24.144 | 25.316 | 27.654 | 3.768 | .024* |
| 9. Elevator power prior to glideslope | .225 | .303 | .274 | .305 | .350 | .414 | 1.140 | .321 |
| 10. Aileron power prior to glideslope | .276 | .326 | .303 | .350 | .490 | .471 | 2.039 | .132 |
| 11. RMS pitch rate deviation prior to glideslope | .485 | .551 | .526 | .667 | .705 | .750 | .956 | .385 |
| 12. RMS roll rate deviation prior to glideslope | 1.327 | 1.444 | 1.396 | 2.027 | 2.359 | 2.335 | 1.016 | .363 |
| 13. Elevator power on glideslope | 4.195 | 3.813 | 3.828 | 4.43 | 5.179 | 4.060 | 1.813 | .165 |
| 14. Ailerson power on glideslope | .456 | .551 | .654 | .775 | 1.379 | 1.134 | 3.418 | .034* |
| 15. Rudder power on glideslope | .680 | .759 | .944 | 1.320 | 1.590 | 1.214 | 3.162 | .004* |
| 16. RMS pitch rate on glideslope | 1.162 | 1.128 | 1.235 | 1.198 | 1.306 | 1.145 | 6.528 | .001* |
| 17. RMS roll rate deviation | 1.343 | 1.455 | 1.770 | 2.231 | 3.123 | 2.783 | 3.413 | .034* |

All F-ratios calculated at $df_{2,212}$

*Indicates significance ($p < .05$).

Analysis of this interaction shows all of the five measures generally associating superior performance with the clear ceiling/visibility conditions.

*Subject Effects.* Significant multivariate subject effects were demonstrated in all of the maneuvers studied. These subject differences were also manifested in nearly all of the univariate analyses of the individual dependent measures. No overall performance hierarchy for the subjects was established, because this information was not pertinent to this study.

*Effect Strengths.* In an attempt to determine the relative strengths of the various independent variable main and interactive effects upon the subjects' performances on the five maneuvers, percentages of nonerror sums of squares were computed for each measure registering univariate significance following a significant multivariate test. Table 7 presents this information for the aerobatic maneuvers: the loop, aileron roll, and the barrel roll. In these maneuvers, the subject effects were most prominent. Consistently, subject differences accounted for the largest portion of the performance variability on each measure. This percentage ranged from 15 to 89 percent of the total variability in the performances of these maneuvers. The percentages for the field-of-view and motion factors were highly variable from measure to measure. The values ranged from 2 to 16 percent for the FOV factor and from .4 to 12 percent for the platform motion factor. The final factor, the G-seat, was considerably more consistent across dependent measures and across maneuvers. The percentage of the performance variability due to the G-seat ranged from .04 to 2 percent, which was dramatically lower than the other factors.

*Table 7.* **Percentages of Nonerror Sums of Squares for the Loop, the Aileron Roll and the Barrel Roll Maneuvers**

| | Source | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A(FOV) | B(MOT) | C(G-Seat) | S(Subj) | AB | AC | BC | ABC |
| | | **Loop** | | | | | | |
| 5. Total score | 3.28 | 12.38* | 2.78 | 43.85* | 12.17* | 2.58 | 4.69 | 18.26 |
| 7. RMS pitch deviation | 2.62 | 6.36 | 1.69 | 54.11* | 6.29* | 4.81 | 6.08 | 18.04 |
| | | **Aileron Roll** | | | | | | |
| 2. Average score of bankin and bankout | 16.34* | 8.10 | .93 | 15.17 | 8.96 | 8.21 | 15.57 | 26.71 |
| 11. Elevator power during roll | 8.94* | 5.65 | 1.45 | 66.78* | 2.83 | 6.79 | 3.65 | 3.92 |
| 13. RMS pitch rate deviation during roll | 3.20* | .40 | .42 | 87.38* | .27 | 1.59 | 2.12 | 4.62 |
| | | **Barrel Roll** | | | | | | |
| 1. Elevator power | 5.56* | 2.18 | .04 | 78.71* | 1.95 | 2.82 | 3.37 | 5.38 |
| 2. Aileron power | 2.62* | 1.07 | .48 | 89.38* | .89 | 1.64 | 1.41 | 2.51 |
| 5. RMS roll rate deviation | 8.95* | 3.64* | .23 | 75.53* | 2.84 | 2.62 | 1.59 | 4.60 |
| 8. RMS pitch-error bottom half | 7.76* | 1.58 | .30 | 75.36* | 2.73 | 1.27 | 3.92 | 7.09 |

*Indicates univariate significance ($p < .05$) was also present.

Table 8 provides percentage information for the GCA maneuver. Subject effects were again most prominent across the various dependent measures. The subject effect sizes ranged from 15 to 74 percent of the nonerror variability. The ceiling/visibility variable, added in this maneuver, also produced relatively large effect strengths. In this maneuver, the percentage values ranged from .4 to 47 percent of the performance variability. The percentage values for the FOV factor in the GCA were somewhat reduced from the values exhibited in the aerobatic maneuvers. In this maneuver, the FOV percentages ranged from .17 to 6 percent of the nonerror variability. The motion factor recorded similar percentages on this maneuver as in previously reported maneuvers, within the range from .25 to 8 percent. The G-seat percentages were somewhat elevated in this maneuver ranging from .03 to 8 percent, dependent upon the specific measure observed. The motion by ceiling/visibility interaction which was found to be significant in the GCA maneuver also shows some enlargement in the percentages of nonerror variability for the various measures. The values for this index range from .07 to 6 percent.

Table 9 depicts the effect strength information for the overhead pattern maneuver. Again, subject effects were the most prominent effect noted, varying between 4 and 74 percent dependent upon the measure. The ceiling/visibility factor also frequently accounted for a relatively large portion of the nonerror variability, between .03 and 54 percent. The percentages associated with the FOV factor were also highly variable, ranging from .12 to 40 percent. Similarly, the motion factor registered wide variability in its effect strengths (.08 to 17 percent). The G-seat percentages, however, were again very consistent in magnitude, varying between .01 to 3 percent.

## IV. DISCUSSION OF STUDY II

Because of the importance of information regarding the effects of simulator design configurations upon pilot performance to the Air Force and other agencies involved in flight simulation, it is appropriate that the results of this study be placed in proper perspective. The results of this study concern only the performance of experienced pilots and cannot be generalized to student pilot behaviors or to the training situation in general. In addition, this effort evaluated the effects of the cueing devices within the context of the ASPT. Other simulators representing different hardware design features or software methods may or may not produce the same sort of results. Finally, the effects of these cue enhancement devices (platform

*Table 8.* **Percentages of Nonerror Sums of Squares for the GCA Maneuver**

| | Source | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | A (FOV) | B (MOT) | C (G-seat) | D (C/V) | S (Subj) | AB | AC | BC | AD | BD | CD | ABC | ABD | ACD | BCD | ABCD |
| 1. Total score | .17 | 1.49 | 1.27 | 6.76* | 74.53* | 1.70 | 1.49 | 1.04 | .71 | 1.15 | .77 | 2.61 | 1.67 | 1.08 | 1.27 | 2.28 |
| 2. Touchdown airspeed | 6.25 | 1.74 | .28 | .40 | 61.53* | 6.28 | 2.39 | 5.28 | 10.57* | 2.05 | 4.10 | 19.28 | 2.64 | 6.30 | 3.62 | 12.31 |
| 3. Touchdown heading | .48 | 1.33 | 1.20 | 10.73* | 20.17* | 4.99 | 1.95 | 1.29 | 1.43 | .62 | 1.47 | 13.20 | 1.41 | 20.12 | 8.45 | 11.18 |
| 5. RMS altitude deviation | .39 | 2.49 | 3.19 | 10.30* | 59.04* | 2.72 | 2.11 | 1.24 | .39 | .34 | 3.65 | 3.31 | 3.18 | .80 | 1.81 | 5.05 |
| 6. RMS airspeed deviation | .98 | 1.30 | 6.73* | 22.32* | 43.02* | 1.08 | .87 | .29 | 2.58 | .07 | .09 | 7.68 | 2.84 | 1.23 | 1.21 | 7.69 |
| 7. RMS centerline deviation | .34 | 1.92 | .86 | 7.22* | 74.91* | 2.15 | 1.99 | .74 | .11 | .67 | 1.15 | 2.71 | .61 | 1.67 | 1.05 | 1.91 |
| 8. RMS glidepath deviation | .52 | .25 | 8.38* | 3.26* | 44.47* | 3.68 | 4.85 | 2.05 | 1.79 | 6.05* | .62 | 10.52 | 3.07 | 1.64 | 3.86 | 5.00 |
| 9. Elevator power prior to glideslope | 4.19 | 8.24* | 1.48 | 14.37* | 15.43* | 2.80 | 3.20 | 6.56 | .07 | 2.70 | 1.13 | 9.80 | 4.52 | 9.24 | 5.20 | 11.07 |
| 10. Aileron power prior to glideslope | .58 | 7.12* | .58 | 19.91* | 54.16* | .65 | 1.76 | 2.26 | 1.56 | 2.04 | 1.35 | 2.90 | .45 | 1.05 | .83 | 2.79 |
| 11. RMS pitch rate deviation prior to glideslope | .46 | 4.03* | .98 | 47.66* | 22.65* | 2.06 | 2.12 | 2.24 | .43 | 1.12 | .03 | 4.29 | .80 | 2.94 | 2.25 | 5.92 |
| 12. RMS roll rate deviation prior to glideslope | 1.98 | 2.35 | .15 | 44.13* | 38.75* | .68 | .39 | 1.89 | 2.00 | .69 | 1.28 | 2.56 | 1.89 | .64 | .12 | .49 |
| 13. Aileron power on glideslope | 2.32 | 2.63 | .40 | 4.69* | 25.52* | 2.66 | 5.48 | 8.52 | 1.67 | 3.52 | .50 | 14.15 | 1.15 | 6.56 | 1.94 | 18.30* |
| 14. Aileron power on glideslope | .23 | 8.69* | .03 | 28.09* | 36.27* | .92 | 2.94 | 3.15 | 1.99 | 4.31* | .50 | 3.18 | 1.67 | 2.30 | 1.32 | 4.43 |
| 15. Rudder power on glideslope | .23 | .93 | .36 | 15.28* | 63.52* | .78 | 4.14* | .87 | .85 | 2.46* | 1.00 | 1.99 | 1.73 | 1.76 | 1.11 | 3.00 |
| 16. RMS pitch rate deviation on glideslope | 1.13 | .49 | 1.55 | .85 | 68.46* | 3.20 | 2.96 | 2.00 | .99 | 6.03* | .22 | 4.18 | .75 | 2.43 | .98 | 3.78 |
| 17. RMS roll rate deviation on glideslope | 2.84* | 5.29* | .24 | 34.28* | 41.92* | 1.08 | 1.61 | 1.79 | .37 | 2.83* | .52 | 1.83 | 1.53 | .44 | .54 | 2.90 |

*Indicates univariate significance ($p < .05$) was also present.

*Table 9.* **Percentages of Nonerror Sums of Squares for the Overhead Pattern Maneuver**

| Variable | A (FOV) | B (MOT) | C (G-seat) | D (C/V) | S (Subj) | AB | AC | BC | AD | BD | CD | ABC | ABD | ACD | BCD | ABCD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Source | | | | | | | | | | | | | | | |
| 2. RMS pitchout bank deviation | 7.89* | 2.79 | .21 | .40 | 70.60* | .54 | 1.65 | .63 | 1.53 | .44 | .63 | 3.93 | 1.43 | 2.89 | 1.27 | 3.19 |
| 4. Pitchout elevator power | .12 | 1.44 | 2.53 | 4.37* | 63.25* | 1.30 | 1.52 | 3.97 | .32 | 3.23 | .69 | 6.83 | 1.56 | 2.67 | 2.03 | 4.17 |
| 7. RMS roll rate deviation during pitchout | 3.21* | .30 | .10 | .03 | 68.45* | 2.32 | 1.38 | .23 | .70 | 1.89 | 2.82* | 4.43 | 2.21 | .78 | 2.42 | 8.74* |
| 8. RMS Vertical Velocity during downwind | 1.28 | .44 | 1.87 | 17.46* | 46.71* | .44 | 1.38 | .32 | 2.74 | 2.92 | .41 | 9.70* | .99 | 5.46* | 2.42 | 5.46 |
| 9. RMS Downwind altitude deviation | .64 | 1.80 | .51 | 17.19* | 33.25* | 1.34 | 1.82 | 2.21 | 3.93 | 1.19 | .43 | 14.17* | 3.00 | 4.75 | 4.05 | 9.73 |
| 10. Downwind Elevator power | 2.21 | 15.82* | .01 | 22.00* | 36.05* | 1.07 | 5.42 | 1.09 | .24 | 1.06 | .26 | 4.78 | .86 | 3.01 | 1.74 | 4.36 |
| 11. Downwind aileron power | .70 | 1.36 | 1.25 | 13.05* | 65.76* | 1.85 | 1.37 | .84 | .54 | 2.19 | .97 | 2.62 | 1.81 | .42 | 1.43 | 3.82 |
| 12. RMS downwind pitch rate deviation | .38 | 3.82* | .44 | 54.71* | 28.86* | .94 | 1.89 | .22 | .55 | 1.52 | .17 | 1.85 | .38 | 2.13 | 1.06 | 1.08 |
| 13. RMS downwind roll rate deviation | .98 | .27 | .90 | 10.22* | 62.65* | 1.54 | 1.33 | .25 | .50 | 2.98 | .12 | 3.41 | 2.67 | 2.35 | 3.13 | 6.70 |
| 14. RMS final turn bank deviation | 36.56* | .31 | 2.01 | 5.58* | 10.80* | 1.12 | 7.28 | 1.85 | 10.71* | .09 | .89 | 3.60 | 11.05* | 4.15 | .71 | 3.29 |
| 15. RMS final turn airspeed deviation | 4.10 | 2.37 | .46 | 9.42* | 46.97* | 2.70 | 4.31 | 2.65 | .57 | .67 | 1.70 | 7.02 | 3.00 | 5.05 | 2.06 | 6.95 |
| 16. Final turn elevator power | 3.28* | 8.06* | 1.08 | 8.28* | 53.91* | 2.65 | 1.69 | 1.17 | .77 | 1.23 | 1.58 | 5.21 | .97 | 1.83 | 4.66 | 3.62 |
| 17. Final turn aileron power | 2.98* | 14.06* | .16 | 7.46* | 55.71* | .77 | .09 | 1.61 | .74 | .44 | 2.50 | 7.17 | 2.90 | .61 | 1.42 | 1.37 |
| 18. RMS final turn pitch rate | 7.49* | 1.56 | .17 | 4.60* | 54.47* | .79 | 1.93 | 2.13 | 2.34 | 2.08 | 2.79 | 6.61 | .85 | .68 | 1.80 | 9.73* |
| 19. RMS final turn roll rate deviation | .44 | 3.55 | .13 | 20.45* | 36.91* | 1.08 | .93 | 5.10 | 1.91 | 2.63 | .93 | 12.44 | 4.72 | 3.46 | 1.80 | 3.51 |
| 21. RMS final approach course deviation | 40.72* | 2.97* | 3.51 | .15 | 17.68* | 1.44 | 3.04 | .99 | .10 | .08 | .77 | 7.13 | 2.04 | 1.03 | 2.21 | 16.14 |
| 22. RMS final approach airspeed deviation | 8.09* | .30 | 1.66 | 4.94* | 44.05* | 2.73 | .58 | 1.89 | 2.26 | 4.97* | .36 | 8.87 | 7.94* | 2.48 | 1.54 | 7.32 |
| 23. Landing X position | 7.44 | 7.99 | 1.94 | 19.01* | 4.97 | .23 | 3.40 | 4.04 | 5.04 | 1.97 | 1.75 | 9.66 | 6.22 | 5.06 | 2.54 | 18.75 |
| 26. Landing Heading | 3.30 | 9.82* | 1.24 | .27 | 42.27* | 9.40* | 2.92 | 8.55 | 1.00 | .82 | 1.26 | 5.69 | 1.86 | 1.74 | 1.41 | 8.45 |
| 28. Elevator power final turn through landing | .57 | 17.80* | 1.45 | 1.37 | 23.84* | 12.00 | 3.98 | 9.04 | 2.38 | 3.38 | 1.55 | 9.96 | .08 | 5.96 | 1.41 | 5.28 |
| 29. Aileron power final turn through landing | 13.44* | 2.62 | 3.01 | 3.71* | 53.68* | 2.39 | 1.50 | 1.13 | .56 | 2.33 | .18 | .77 | 3.09 | 2.47 | 3.70 | 5.42 |
| 30. Rudder power final turn through landing | 3.37* | 1.08 | .72 | .30 | 74.73* | 1.43 | .56 | 2.90 | .14 | 3.45* | .76 | 4.78 | 1.42 | 2.01 | .22 | 2.13 |
| 31. RMS pitch rate final turn through landing | 30.59* | .16 | 2.35 | .65 | 25.12* | 1.59 | 2.70 | 4.01 | .32 | 3.47 | .60 | 7.68 | 2.70 | 1.78 | 3.51 | 12.74 |
| 32. RMS roll rate final turn through landing | 21.61* | 3.07 | 2.05 | 2.53 | 44.22* | .51 | .89 | 1.26 | 4.08 | 2.13 | .09 | 2.10 | 2.30 | 4.53 | 2.67 | 6.95 |
| 33. RMS vertical velocity final turn through landing | 1.36 | .08 | .78 | 3.71* | 38.01* | 1.75 | .89 | 9.59 | .95 | 6.52 | 1.66 | 13.80* | 4.35 | 4.86 | 1.67 | 10.03 |
| 35. Overall downwind score | 2.92 | 1.26 | .86 | 18.81* | 16.54* | 3.83 | 1.11 | .53 | 3.25 | 4.17* | 1.13 | 14.32* | 7.06* | 10.61* | 2.45 | 11.15 |
| 36. Overall final approach score | 2.93 | 1.41 | 1.88 | 4.03* | 51.47* | .68 | 1.33 | 5.23 | 2.96 | .37 | 2.70 | 7.78 | 1.47 | 3.70 | 2.00 | 10.07 |

*Indicate univariate significance was also found.

motion, G-seat and visual display) are strictly specific to the types of maneuvers being investigated. It seems reasonable to expect that the devices vary in their effectiveness dependent upon the particular portion of the flight regime of the aircraft being simulated.

*System Design Variables.* The field-of-view variable was found to significantly impact pilots' performance on four of the five maneuvers in this study. In the aileron roll, the results suggest that the width of the visual display directly affects the pilots' ability to control the simulated aircraft both in pitch and roll dimensions. While the pilots tended to score better on bank in, out and roll control under full FOV conditions, they seemed to demonstrate superior elevator and hence pitch control when under restricted FOV conditions. One possible explanation for this phenomenon is that the additional peripheral information is useful and important for control of the vehicle in the roll dimension but is irrelevant information for pitch control. Thus, when the extraneous information is removed and concentration is directed toward the front of the vehicle, pitch response is improved. This improvement occurs as a decrease in the amount of effort expended and an increase in the smoothness of the effort used in controlling the simulator.

The same trends concerning the FOV appear in the barrel roll where roll performance tends to be poorer under the most restricted FOV when compared to the larger display sizes. Again, the exception lies in the extent of the pilots' inputs to the elevators. Under the most restricted condition, the elevator inputs become smaller, probably in response to the loss in extraneous signals.

In the overhead pattern maneuver, the loss of visual information was manifested particularly within the pitchout, final turn, and final approach segments. In the pitchout and final turn, the pilots again appeared to be making fewer, less extensive inputs to the elevators thereby resulting in smoother pitch rate scores, but less accurate overall aircraft control. Aileron control in these segments generally was degraded as a function of display size reduction. The more restricted the display became, the poorer the performance in those measures reflecting aileron control. However, the results for the final approach suggested a change in the control strategy used. During the final approach, as the runway came into view, the pilot increased his inputs to the elevators and, in effect, worked harder in an attempt to land the aircraft. However, his overall performance tended to remain degraded in spite of his efforts.

Only one of 17 measures was affected by changes in the FOV in the GCA maneuver. Again, this measure reflected the pilots' ability to maintain the proper lateral stability in this case on the glideslope segment. However, no changes were exhibited in pitch control or control strategies.

*Motion.* The manipulation of the degrees of freedom in the platform motion system resulted in significant performance differences in the loop, the overhead pattern, and the GCA. In the loop, the total score, which was a derived score, exhibited best performance when accompanied by motion. This was the only measure of the seven measures collected which demonstrated any significant differences due to platform motion. Because of this inconsistency, this instance may be an artifact, possibly due to the manner in which the total score was derived. However, other tracking-type studies (Borlace, 1967; Koonce, 1974) have reported enhanced performance with the platform motion operational, and this result may be related to such effects. In these studies, pilot errors were significantly reduced when maneuvers where flown in the simulator with platform motion, as compared to when flown without motion.

The absence of any consistent and reliable motion effect in the two higher G-maneuvers, the loop and the barrel roll, was somewhat surprising. It was initially anticipated that the relatively quick onset and large magnitude of motion cues intrinsic to these maneuvers would tend to highlight any possible performance differences due to motion configurations. Apparently, this was not the case as only the total score variable manifested significance and that in a direction contrary to the vast majority of other measures which were sensitive to platform motion manipulation.

The results of the overhead pattern were considerably more consistent in the trends exhibited. The effects of the motion variable were manifested within the downwind, final turn and final approach segments. In these segments, it appeared that the introduction of motion, either 3 or 6 DOF, fundamentally affected the pilots' pitch control. The amount of pilot input to the elevators in all of these segments was

substantially increased when motion was added. Likewise, pilot inputs to the ailerons were increased in the final turn segment, probably in an attempt to control for the increased instability in the aircraft's movements. The fewer inputs by the pilots under the no-motion condition seemed to result in smoother pilot responses as evidenced by the improved performance on the RMS pitch rate on the downwind segment. In only one case was performance under motion superior to performance without, that being in the landing heading of the vehicle. In this instance, performance with 3 DOF was superior to no-motion performance.

The same general trends were demonstrated in the performance of the GCA. Performance under the no-motion condition was consistently superior to performance under either 3 or 6 DOF motion. Fewer, smoother aileron and elevator inputs were made by the pilots in completing this task when platform motion was absent. However, few reliable differences were found between the 3 and 6 DOF conditions.

*Environmental Variable.* The ceiling/visibility variable demonstrated consistent significant effects upon the two maneuvers wherein it was manipulated. In the overhead pattern, performance on all segments, pitchout, downwind, final turn and final approach to landing, was deleteriously affected when the ceiling and visibility conditions were reduced. The aircraft performance parameters, the pilot input measures and the derived scores were all affected in this manner. The same performance decrements were exhibited in the GCA analysis. Again, all three types of measures were similarly affected. This consistent demonstration (14 out of 17 measures) provided strong evidence that the algorithms used in generating the environmental variable were valid, in that performance was, as anticipated, degraded when environmental conditions deterioriated.

*Interaction.* Only one interaction achieved significance in any of the maneuvers investigated in this study. The first-order platform motion by ceiling/visibility interaction demonstrated significance in the GCA. This interaction suggested that the motion and ceiling/visibility variables combined synergistically when used together. In this maneuver, the interaction was illustrated by differential motion effects dependent upon the environmental conditions. Under clear conditions, the subject pilots tended to perform the flight task better with full motion. In these situations, the performance was generally improved by making more extensive inputs to the ailerons and rudder. This increased activity with the controls, thereby resulted in less smooth rate changes, notably pitch rate and roll rate on glideslope. However, when the task was performed under minimum ceiling/visibility conditions, the pilots appeared to have improved performances without motion cueing. In these cases, the pilots also tended to make fewer control inputs to the ailerons and rudder. Under the ceiling/visibility conditions, the pilots were most probably flying completely on their instruments.

## V. DISCUSSION OF STUDIES I AND II

Several important differences existed between the two studies. One important variation is that the motion, G-seat, and flight dynamic equations of the ASPT were modified during the intervening time period between the studies. Although these modifications were made as "improvements" to the systems from an engineering standpoint, it is uncertain as to what physiological or psychological impact these changes may have caused.

Secondly, several performance measurement routines had been updated in the time between the studies. Again, although the changes were made in the interest of improvement, it is uncertain as to whether the updated versions have become more or less sensitive to the variables under consideration.

Another difference between the studies arises from the fact that a separate visual environment was utilized in each study. The visual environment utilized in the second study represented superior display capabilities not only in the modeling of the ground area within immediate proximity of the airfield but also in the ability to manipulate visual display dimensions.

These differences in the various capabilities of the ASPT, motion, G-seat, performance measurement, and visual display, could have certainly altered the effects of these devices on the pilots' performances. In

spite of the various uncontrolled changes in the simulator, the results of Study II seem to be in general agreement with the data of the earlier study.

Table 10 illustrates the locations of the significant multivariate effects found across all of the maneuvers in the two studies. Within this table, the hyphenated areas represent effects which were not estimated for various specific reasons. Empty spaces represent nonsignificant effects. Inspection of this

*Table 10.* **Comparison of Significant Multivariate Effects Across Study I and Study II Maneuvers**

| | Aileron Roll | | GCA | | Ovhd Pttn | | Slo Flt | Takeoff | Barrel Roll | Loop |
|---|---|---|---|---|---|---|---|---|---|---|
| Effect | II | I | II | I | II | I | I | I | II | II |
| A(MOT) | | * | * | * | * | * | * | * | 0 | * |
| B(FOV) | * | * | * | | * | | | | * | |
| C(G-Seat) | | | | * | | | | * | | |
| D(C/V) | – | – | * | * | * | * | – | * | – | – |
| E(Winds) | – | – | – | * | – | * | – | * | – | – |
| F(Turb) | – | | – | * | – | | | | – | – |
| S(Block) | * | * | * | * | * | * | * | * | * | * |
| AB(MOTxFOV) | | | | * | | | | * | | 0 |
| AC | | | | | | * | | * | | |
| AD | – | – | * | | | | – | | – | – |
| AE | – | – | – | | – | | – | | – | – |
| AF | – | | – | * | – | * | | * | – | – |
| BC | | | | | | | | | | |
| BD | – | – | | * | | | – | | – | – |
| BE | – | – | – | | – | | – | | – | – |
| BF | – | | – | | – | | – | | – | – |
| CD | – | – | | * | | 0 | – | | – | – |
| CF | – | | – | | – | | – | | – | – |
| DE | – | – | | | – | | – | | – | – |
| DF | – | – | – | | – | | – | | – | – |
| EF | – | – | – | 0 | – | | – | | – | – |
| ABD | – | – | | | | | – | | – | – |
| ABE | – | – | – | 0 | – | | – | | – | – |
| ABF | – | 0 | – | | – | | – | | – | – |
| ACD | – | – | | | | | – | | – | – |
| ACE | – | – | – | | – | | – | | – | – |
| ACF | – | – | – | | – | | – | | – | – |
| ADE | – | | – | | – | | | | – | – |
| ADF | – | – | – | | – | | – | | – | – |
| AEF | – | – | – | | – | | – | | – | – |
| BCD | – | – | | * | | * | – | * | – | – |
| BCE | – | – | – | | – | | – | | – | – |
| BDF | – | – | – | | – | | – | | – | – |
| BEF | – | – | – | | – | | – | | – | – |
| CDE | – | – | – | | – | | – | | – | – |
| CDF | – | – | – | | – | | – | 0 | – | – |
| CEF | – | – | – | | – | | – | | – | – |
| DEF | – | – | – | | – | | – | | – | – |
| ABC | | | | | | | | | | |
| ABCD | – | – | | – | – | – | – | – | – | – |

*Denotes significance $p < .05$.

0 Denotes significance $p < .10$.

– Represent effects not estimated.

MOT = Motion.
FOV = Field-of-View.
TURB = Turbulence.
SLO FLT = Slow Flight.
OVHD PTTN = Overhead Pattern.
GCA = Ground Controlled Approach.

table reveals that significant subject differences were present in every maneuver. The consistency in this effect strongly suggests that pilots responses to system and environmental alterations are highly individualistic. It also strongly suggests that no one model of piloting behaviors is generalizable to the population of expert pilots, in that various control strategies are employed.

It is also apparent by viewing the results of the two studies that the algorithms used in generating the environmental effects in the ASPT seem to be properly constructed. The simulated weather factors affected performance in the directions which were anticipated, i.e., increasing winds and turbulence correspondingly decreased performance. Similarly decreasing the C/V conditions caused poorer performances. Table 11 depicts the location of the measures across the two studies, which demonstrated significant univariate C/V effects. Since the environmental variables precipitated results in the expected directions, the environmental factors became benchmarks against which the effects of the system variables were measured.

The system variables showed significant impacts in every maneuver. One system variable, platform motion, demonstrated multivariate significance in 8 of the 10 total maneuvers in the two studies. In only one multivariate case, the loop in the second study, was performance not superior when platform motion was absent. Table 12 presents the motion effects on the specific dependent measures which were common to both studies. These measures represent portions of the measurement sets used in the analyses of the overhead pattern, the GCA, and the aileron roll maneuvers. These three maneuvers are the only maneuvers to have been completed by subjects in both Studies I and II. In this Table, the mean performances on each measure for both studies are listed, including whether or not univariate signfiicance was achieved. Furthermore, the measures are categorized into either a system output, pilot input or derived score classification. This was performed in an attempt to determine which type of variable was most responsive to either environmental or simulator design variations. In the first maneuver of the Table, the overhead pattern, a large majority of the univariate significant differences fell under the category of pilot input scores. In this maneuver, it seems that platform motion causes the greatest impact in the pilots' control strategy, rather than in the criterion-referenced aircraft parameters.

In the ground controlled approach, however, this distinction is not as apparent. Several significant differences were evidenced in all of the categories with the majority of instances in the system output and pilot input categories.

In the aileron roll maneuver, the only significant differences recorded fell into the category of system output measures and then only in the first study.

The second system configuration variable, field-of-view, demonstrated a reliable impact in five of the 10 maneuvers studied as shown in Table 10. A univariate comparison between the two studies is shown in Table 13.

In the overhead pattern portion of this table, no clear-cut difference exists between the incidence of significance in the system output or pilot input categories. The same was true in the aileron maneuver. However, in the GCA, significance occurred more frequently under the pilot input category.

The final system variable, the G-seat evidenced multivariate effects in two of the 10 maneuvers investigated across the two studies (Table 10). In Table 14, univariate comparisons were made between the means of the dependent measures common to the two studies. In the overhead pattern, no immediate distinction is obvious between the sensitivity of system output, or pilot input to variations in the G-seat's operation. In the GCA, however, every case of significant difference was found to occur under the system output classification in both studies. In the aileron roll, no significance due to the G-seat was found either in the first or the second study.

Overall, the results of the two studies showed surprising consistency in terms of the nature and direction of the effects of the system and environmental variables. The results seem to indicate that all of the variables investigated, with the possible exception of the G-seat, directly or indirectly influence expert pilot performances in the variety of maneuvers investigated. However, the data also indicate that in comparison to subject differences and environmental factors the design variables are of lesser importance. This was effectively demonstrated, not only in the frequency of reliable differences found, but also in the relative effect strengths of these factors.

*Table 11.* **Ceiling/Visibility Effects Upon Individual Dependent Measures Common to Studies I and II**

| Source | $\overline{X}$ (Clear) I | $\overline{X}$ (Clear) II | $\overline{X}$ (Minimum) I | $\overline{X}$ (Minimum) II | Significance Found |
|---|---|---|---|---|---|
| **360° Overhead Pattern** | | | | | |
| **System Output** | | | | | |
| 1. RMS pitchout bank deviation | 11.4 | 3.67 | 9.95 | 3.50 | |
| 2. RMS pitchout altitude deviation | 36.3 | 38.50 | 47.3 | 39.25 | 0 |
| 3. RMS downwind altitude deviation | 35.8 | 30.61 | 44.6 | 41.65 | *0 |
| 4. RMS final turn bank deviation | 9.83 | 7.36 | 11.20 | 8.19 | *0 |
| 5. RMS final turn airspeed deviation | 5.07 | 3.37 | 6.60 | 4.19 | *0 |
| 6. RMS glidepath deviation | 1.09 | 1.22 | 1.22 | 1.32 | |
| 7. RMS centerline deviation | 110 | 54.37 | 154 | 57.75 | |
| 8. RMS final approach airspeed deviation | 4.23 | 3.81 | 5.37 | 4.92 | *0 |
| **Pilot Input** | | | | | |
| 1. Pitchout elevator power | 1.81 | 2.01 | 1.97 | 2.32 | * |
| 2. Pitchout aileron power | .47 | 1.21 | .60 | 1.26 | 0 |
| 3. Downwind elevator power | 1.71 | .95 | 2.46 | 1.34 | *0 |
| 4. Downwind aileron power | 1.07 | .53 | 1.36 | .79 | *0 |
| 5. Final turn elevator power | 1.47 | .79 | 1.79 | 1.02 | *0 |
| 6. Final turn aileron power | .74 | .69 | .87 | .87 | *0 |
| 7. Final through landing elevator power | 2.86 | 2.35 | 3.18 | 2.48 | |
| 8. Final through landing aileron power | 1.77 | 1.02 | 2.14 | 1.17 | *0 |
| 9. Final through landing rudder power | 3.63 | .41 | 4.35 | .45 | *0 |
| **Derived** | | | | | |
| 1. Downwind score | 70.4 | 70.06 | 62.9 | 56.24 | *0 |
| 2. Landing score | 77.1 | 81.10 | 75.8 | 81.05 | |
| **Ground Controlled Approach** | | | | | |
| **System Output** | | | | | |
| 1. RMS altitude deviation | 40.4 | 22.12 | 38.8 | 25.90 | * |
| 2. RMS airspeed deviation | 7.59 | 1.53 | 2.59 | 1.90 | * |
| 3. RMS centerline deviation | 95.0 | 54.13 | 108 | 68.58 | *0 |
| 4. RMS glidepath deviation | 34.7 | 23.76 | 37.2 | 25.69 | * |
| **Pilot Input** | | | | | |
| 1. Elevator power prior to glideslope | .429 | .26 | .469 | .35 | * |
| 2. Aileron power prior to glideslope | .46 | .30 | .46 | .43 | * |
| 3. Elevator power after glideslope | 4.28 | 3.94 | 4.11* | 4.55 | * |
| 4. Aileron power after glideslope | 1.54 | .55 | 1.81 | 1.09 | * |
| **Derived** | | | | | |
| 1. Total Score | 76.9 | 62.97 | 77.6 | 54.73 | *0 |

*Indicates significance ($p < .05$). found in second study.

0 Indicates significance ($p < .05$) found in first study.

I,II Relate to Studies I and II, respectively

*Table 12.* **Motion Effects Upon Individual Dependent Measures Common to Studies I and II**

| Source | $\overline{X}$(0 DOF) I | $\overline{X}$(0 DOF) II | $\overline{X}$(3 DOF) I | $\overline{X}$(3 DOF) II | $\overline{X}$(6 DOF) I | $\overline{X}$(6 DOF) II | Significance Found |
|---|---|---|---|---|---|---|---|
| **360° Overhead Pattern** | | | | | | | |
| **System Output** | | | | | | | |
| 1. RMS pitchout bank deviation | 10.1 | 3.87 | 11.20 | 3.60 | 10.8 | 3.29 | |
| 2. RMS pitchout altitude deviation | 36.9 | 41.38 | 40.6 | 37.9 | 47.8 | 37.36 | |
| 3. RMS downwind altitude deviation | 34.0 | 36.55 | 41.4 | 33.76 | 45.3 | 38.07 | 0 |
| 4. RMS final turn bank deviation | 9.95 | 7.66 | 10.6 | 7.90 | 11.0 | 7.76 | |
| 5. RMS final turn airspeed deviation | 5.68 | 3.83 | 6.14 | 4.01 | 5.69 | 3.51 | |
| 6. RMS glidepath deviation | 1.14 | 1.32 | 1.12 | 1.18 | 1.20 | 1.31 | |
| 7. RMS centerline deviation | 128 | 65.79 | 134 | 54.59 | 134 | 47.80 | |
| 8. RMS final approach airspeed deviation | 4.88 | 4.25 | 4.73 | 4.56 | 4.79 | 4.29 | |
| **Pilot Input** | | | | | | | |
| 1. Pitchout elevator power | 2.16 | 2.04 | 1.72 | 2.19 | 1.79 | 2.26 | |
| 2. Pitchout aileron power | .439 | 1.17 | .513 | 1.25 | .666 | 1.28 | 0 |
| 3. Downwind elevator power | 2.22 | .994 | 1.74 | 1.169 | 2.30 | 1.349 | 0 |
| 4. Downwind aileron power | .895 | .608 | 1.17 | .701 | 1.58 | .692 | *0 |
| 5. Final turn elevator power | 1.55 | .772 | 1.47 | .903 | 1.88 | 1.053 | |
| 6. Final turn aileron power | .605 | .615 | .830 | .837 | .987 | .902 | *0 |
| 7. Final through landing elevator power | 3.28 | 2.091 | 2.74 | 2.528 | 3.04 | 2.631 | * |
| 8. Final through landing aileron power | 1.70 | 1.03 | 2.05 | 1.18 | 2.12 | 1.07 | |
| 9. Final through landing rudder power | 4.40 | .393 | 3.48 | .454 | 4.09 | 0.457 | |
| **Derived** | | | | | | | |
| 1. Downwind score | 70.2 | 61.35 | 65.5 | 65.59 | 64.2 | 62.51 | |
| 2. Landing score | 78.1 | 80.07 | 76.2 | 81.32 | 75.2 | 81.83 | |
| **Ground Controlled Approach** | | | | | | | |
| **System Output** | | | | | | | |
| 1. RMS altitude deviation | 33.2 | 23.19 | 41.2 | 25.31 | 44.3 | 23.53 | 0 |
| 2. RMS airspeed deviation | 2.40 | 1.70 | 2.44 | 1.78 | 2.92 | 1.67 | 0 |
| 3. RMS centerline deviation | 96.7 | 59.53 | 102 | 66.55 | 106 | 57.98 | * |
| 4. RMS glidepath deviation | 36.3 | 24.73 | 35.6 | 24.40 | 36.0 | 25.05 | |
| **Pilot Input** | | | | | | | |
| 1. Elevator power prior to glideslope | .091 | .26 | .113 | .32 | .123 | .34 | * |
| 2. Aileron power prior to glideslope | .379 | .31 | .395 | .40 | .572 | .38 | *0 |
| 3. Elevator power after glideslope | 8.56 | 4.31 | 6.83 | 4.49 | 9.20 | 3.94 | |
| 4. Aileron power after glideslope | 4.29 | .61 | 3.70 | .96 | 4.61 | .89 | * |
| **Derived** | | | | | | | |
| 1. Total score | 27.3 | 60.76 | 24.3 | 55.84 | 22.7 | 9.20 | 0 |
| **Aileron Roll** | | | | | | | |
| **System Output** | | | | | | | |
| 1. RMS bank-in deviation | 1.54 | 1.17 | 2.12 | 1.01 | 2.50 | 1.29 | 0 |
| 2. RMS bank-out deviation | 2.86 | 2.80 | 3.84 | 2.73 | 3.76 | 3.08 | 0 |
| 3. RMS roll acceleration during bank-in | 10.2 | 2.79 | 13.7 | 2.70 | 14.0 | 3.32 | |

Table 12 (*Continued*)

| Source | $\overline{X}$(0 DOF) I | II | $\overline{X}$(3 DOF) I | II | $\overline{X}$(6 DOF) I | II | Significance Found |
|---|---|---|---|---|---|---|---|
| **Pilot Input** | | | | | | | |
| 1. Aileron power bank-in | 1.18 | .171 | 1.92 | .181 | 1.95 | .178 | |
| 2. Aileron power roll | 1.01 | 5.09 | 1.43 | 4.18 | 1.49 | 4.70 | |
| 3. Aileron power bank-out | .873 | 4.07 | 1.18 | 3.17 | 1.53 | 2.63 | |
| **Derived** | | | | | | | |
| 1. Roll score | 38.8 | 82.98 | 36.2 | 85.64 | 40.5 | 80.83 | |

*Indicates significance ($p < .05$) found in second study.

[0]Indicates significance ($p < .05$) found in first study.

[I,II]Relate to Study I and Study II, respectively.

*Table 13.* **Field-of-View Effects Upon Individual Dependent Measures Common to Studies I and II**

| Source | $\overline{X}$ (Full) I | II | $\overline{X}$ (36x144) I | II | $\overline{X}$ (36x48) I | II | Significance Found |
|---|---|---|---|---|---|---|---|
| | | | **360° Overhead Pattern** | | | | |
| **System Output** | | | | | | | |
| 1. RMS pitchout bank deviation | 10.4 | 4.14 | – | 3.29 | 11.0 | 3.32 | * |
| 2. RMS pitchout altitude deviation | 39.4 | 39.650 | – | 38.10 | 44.1 | 38.89 | |
| 3. RMS downwind altitude deviation | 39.3 | 35.50 | – | 37.62 | 41.1 | 35.26 | * |
| 4. RMS final turn bank deviation | 9.62 | 6.40 | – | 7.92 | 11.5 | 9.01 | |
| 5. RMS final turn airspeed deviation | 5.92 | 3.43 | – | 3.82 | 5.75 | 4.09 | |
| 6. RMS glidepath deviation | 1.04 | 1.24 | – | 1.19 | 1.26 | 1.38 | |
| 7. RMS centerline deviation | 99.1 | 23.55 | – | 53.93 | 165 | 90.70 | * |
| 8. RMS final approach airspeed deviation | 4.09 | 3.92 | – | 3.81 | 5.51 | 5.26 | * |
| **Pilot Input** | | | | | | | |
| 1. Pitchout elevator power | 1.91 | 2.13 | – | 2.19 | 1.87 | 2.17 | |
| 2. Pitchout aileron power | .48 | 1.20 | – | 1.22 | .59 | 1.28 | |
| 3. Downwind elevator power | 2.04 | 1.07 | – | 1.15 | 2.13 | 1.22 | |
| 4. Downwind aileron power | 1.09 | .65 | – | .64 | 1.34 | .70 | |
| 5. Final elevator power | 1.62 | .96 | – | .95 | 1.65 | .80 | * |
| 6. Final aileron power | .72 | .86 | – | .75 | .89 | .73 | |
| 7. Final through landing elevator power | 3.03 | 2.39 | – | 2.38 | 3.02 | 2.47 | * |
| 8. Final through landing elevator power | 1.84 | .90 | – | 2.13 | 2.07 | 1.26 | * |
| 9. Final through landing rudder power | 3.96 | .37 | – | .42 | 4.02 | .50 | * |
| **Derived** | | | | | | | |
| 1. Downwind score | 70.5 | 66.40 | – | 63.32 | 62.9 | 59.73 | |
| 2. Landing score | 76.5 | 81.33 | – | 81.83 | 76.4 | 80.16 | |
| | | | **Ground Controlled Approach** | | | | |
| **System Output** | | | | | | | |
| 1. RMS altitude deviation | 37.2 | 24.24 | – | 23.50 | 42.0 | 24.30 | |
| 2. RMS airspeed deviation | 24.6 | 1.76 | – | 1.75 | 27.1 | 1.66 | |
| 3. RMS centerline deviation | 104 | 61.67 | – | 63.09 | 99.4 | 59.30 | |
| 4. RMS glidepath deviation | 37.1 | 24.48 | – | 25.27 | 34.8 | 24.43 | |

Table 13 (*Continued*)

| Source | $\overline{X}$ (Full) I | $\overline{X}$ (Full) II | $\overline{X}$ (36x144) I | $\overline{X}$ (36x144) II | $\overline{X}$ (36x48) I | $\overline{X}$ (36x48) II | Significance Found |
|---|---|---|---|---|---|---|---|
| **Pilot Input** | | | | | | | |
| 1. Elevator power prior to glideslope | .42 | .34 | – | .29 | .47 | .30 | |
| 2. Aileron power prior to glideslope | .39 | .37 | – | .35 | .53 | .38 | 0 |
| 3. Elevator power after glideslope | 4.21 | 4.45 | – | 4.34 | 4.18 | 3.95 | |
| 4. Aileron power after glideslope | 1.58 | .85 | – | .79 | 1.76 | .83 | |
| **Aileron Roll** | | | | | | | |
| **System Output** | | | | | | | |
| 1. RMS bank-in deviation | 1.82 | 1.10 | – | 1.09 | 2.11 | 1.28 | |
| 2. RMS bank-out deviation | 2.56 | 2.22 | – | 2.92 | 3.18 | 3.42 | |
| 3. RMS roll acceleration during bank-in | 9.67 | 3.28 | – | 2.30 | 13.1 | 3.22 | 0 |
| **Pilot Input** | | | | | | | |
| 1. Aileron power bank-in | .99 | .21 | – | .13 | 1.92 | .18 | 0 |
| 2. Aileron power roll | .79 | 5.02 | – | 4.46 | 1.52 | 4.50 | |
| 3. Aileron power bank-out | 1.24 | 2.34 | – | 3.41 | 1.08 | 4.11 | |
| **Derived** | | | | | | | |
| 1. Roll score | 35.3 | 85.84 | – | 84.32 | 40.5 | 79.30 | * |

*Indicates significance ($p < .05$) found in second study.

0 Indicates significance ($p < .05$) found in first study.

– Indicates no data.

I,II Indicates Study I or Study II.

*Table 14.* **G-Seat Effects Upon Individual Dependent Measures Common to Studies I and II**

| Source | $\overline{X}$ (Off) I | $\overline{X}$ (Off) II | $\overline{X}$ (Seat Pan) I | $\overline{X}$ (Seat Pan) II | $\overline{X}$ (On) I | $\overline{X}$ (On) II | Significance Found |
|---|---|---|---|---|---|---|---|
| **360° Overhead Pattern** | | | | | | | |
| **System Output** | | | | | | | |
| 1. RMS pitchout bank deviation | 11.7 | 3.61 | – | 3.65 | 9.67 | 3.50 | |
| 2. RMS pitchout altitude deviation | 42.3 | 38.04 | – | 35.00 | 41.3 | 43.59 | 0 |
| 3. RMS downwind altitude deviation | 40.8 | 35.90 | – | 35.09 | 39.6 | 37.39 | * |
| 4. RMS final turn bank deviation | 10.60 | 7.48 | – | 8.09 | 10.50 | 7.75 | |
| 5. RMS final turn airspeed deviation | 5.89 | 3.66 | – | 3.81 | 5.78 | 3.88 | |
| 6. RMS glidepath deviation | 1.27 | 1.25 | – | 1.23 | 1.03 | 1.33 | |
| 7. RMS centerline deviation | 159 | 52.20 | – | 67.28 | 105 | 48.71 | |
| 8. RMS final approach airspeed deviation | 4.89 | 4.01 | – | 4.29 | 4.71 | 4.79 | |
| **Pilot Input** | | | | | | | |
| 1. Pitchout elevator power | 1.68 | 2.14 | – | 2.32 | 2.09 | 2.03 | |
| 2. Pitchout aileron power | .52 | 1.21 | – | 1.27 | .55 | 1.22 | |
| 3. Downwind elevator power | 1.94 | 1.15 | – | 1.16 | 2.23 | 1.14 | |
| 4. Downwind aileron power | 1.16 | .62 | – | .66 | 1.27 | .71 | |
| 5. Final turn elevator power | 1.52 | .85 | – | .94 | 1.74 | .92 | |

Table 14 (*Continued*)

| Source | $\overline{X}$(Off) I | $\overline{X}$(Off) II | $\overline{X}$ (Seat Pan) I | $\overline{X}$ (Seat Pan) II | $\overline{X}$ (On) I | $\overline{X}$ (On) II | Significance Found |
|---|---|---|---|---|---|---|---|
| 6. Final turn aileron power | .81 | .76 | – | .80 | .79 | .78 | |
| 7. Final through landing elevator power | 2.78 | 2.34 | – | 2.50 | 3.27 | 2.40 | 0 |
| 8. Final through landing aileron power | 2.03 | 1.03 | – | 1.06 | 1.87 | 1.19 | |
| 9. Final through landing rudder power | 4.0 | .42 | – | .41 | 3.98 | .46 | |
| **Derived** | | | | | | | |
| 1. Downwind score | 67.2 | 63.42 | – | 64.81 | 66.1 | 61.22 | |
| 2. Landing score | 76.0 | 81.28 | – | 81.47 | 77.0 | 80.47 | |
| **Ground Controlled Approach** | | | | | | | |
| **System Output** | | | | | | | |
| 1. RMS altitude deviation | 44.0 | 24.48 | – | 25.01 | 35.2 | 22.55 | 0 |
| 2. RMS airspeed deviation | 2.70 | 1.69 | – | 1.86 | 2.48 | 1.61 | * |
| 3. RMS centerline deviation | 108 | 64.84 | – | 59.18 | 95.3 | 60.05 | 0 |
| 4. RMS glidepath deviation | 37.3 | 25.20 | – | 26.34 | 34.6 | 22.64 | * |
| **Pilot Input** | | | | | | | |
| 1. Elevator power prior to glideslope | .42 | .30 | – | .33 | .47 | .30 | |
| 2. Aileron power prior to glideslope | .48 | .36 | – | .38 | .44 | .36 | |
| 3. Elevator power after glideslope | 3.97 | 4.13 | – | 4.26 | 4.42 | 4.35 | |
| 4. Aileron power after glideslope | 1.66 | .82 | – | .81 | 1.69 | .83 | |
| **Derived** | | | | | | | |
| 1. Total score | 23.5 | 58.19 | – | 56.50 | 26.0 | 61.10 | |
| **Aileron Roll** | | | | | | | |
| **System Output** | | | | | | | |
| 1. RMS bank-in deviation | 2.17 | 1.18 | 2.12 | 1.22 | 1.87 | 1.08 | |
| 2. RMS bank-out deviation | 3.75 | 2.24 | 3.39 | 3.18 | 3.32 | 3.19 | |
| 3. RMS roll acceleration during bank-in | 13.1 | 3.59 | 12.9 | 2.91 | 12.5 | 2.32 | |
| **Pilot Input** | | | | | | | |
| 1. Aileron power bank-in | 2.03 | .205 | 1.43 | .17 | 1.60 | .15 | |
| 2. Aileron power roll | 1.49 | 5.26 | 1.22 | 4.49 | 1.23 | 4.23 | |
| 3. Aileron power bank-out | 1.45 | 2.61 | 1.16 | 3.94 | .968 | 3.31 | |
| **Derived** | | | | | | | |
| 1. Roll score | 42.8 | 83.86 | 36.3 | 82.26 | 36.4 | 83.34 | |

*Indicates significance ($p < .05$) found in second study.

[0]Indicates significance ($p < .05$) found in first study.

–Indicates no data collected.

[I,II]Relate to Study I and Study II, respectively.

## VI. SUMMARY AND CONCLUSIONS

The results of these two investigations (I & II) have provided a substantial amount of information regarding the relative influences of various system design and simulated environmental factors upon expert pilot behaviors in the simulator. Although several differences between the two studies existed, generally the findings were consistent across the investigations.

One of the most important conclusions based upon the findings of these studies regards the apparent hierarchy of the various factors which were manipulated. The largest and most consistent factor affecting performance is that of individual differences. In comparison with this factor, all other variable effects seem small. The fact that people are different is nothing new or surprising; however, it strongly suggests that individual pilots respond to simulator configurations differently and disconfirms the hypothesis that any simple linear model of piloting behaviors is sufficient to describe the processes involved in controlling an aircraft.

The results showed that simulated environmental factors were also demonstrated to be functioning in the anticipated manner, that is, as the simulated weather conditions deteriorated, the flight performances became poorer. This provided some degree of face validity to the construction and implementation of the algorithms used in generating the environmental settings. Additionally, the environmental factors were seen to interact with the system configuration variables in certain instances to cause differential performances on several flight tasks. The effects of the environmental variables were also demonstrated to be relatively large in size when viewed in comparison with the effects of the simulator design configuration variables. The effects of the environmental variables also seemed to be equally dispersed among the several categories of dependent measures which were collected.

The simulator configuration variables also seemed to lend themselves to the establishment of an effect hierarchy. The most frequently occurring effect across the two studies belonged to the platform motion variable. The effects of this variables seemed to be generally consistent in that the addition of platform motion to the flight task normally degraded the performance on that task. However, it was not clear when weighing the results of both studies whether performance was more frequently inferior under the 3 DOF or the 6 DOF situation. The differences caused by the motion variable were often manifested in measurements particularly sensitive to change in pitch control. Furthermore, in some cases, the changes were more frequently recorded within the pilot input category of the dependent measures suggesting that this variable, while often not strong enough to alter the overall performance of the vehicle does, however, cause changes in the pilots' controlling strategy.

The motion variable, while demonstrating more frequent significant impacts than the other two system variables, generally was not larger in size than the effects due to the field-of-view variable. Both factors accounted for approximately 1 to 10 percent of the performance variability. The field-of-view variable manifested consistent significant impacts upon the subjects' performance of four maneuvers in the two studies: the aileron roll (twice), the barrel roll, and portions of the overhead pattern maneuver. The performance measurements which seemed to be most strongly affected by changes in the field-of-view of the visual display represented scores sensitive to changes in the roll dimension of the aircraft. Measures reflecting changes in the pitch status of the simulator were also affected. However, these measures did not seem to be impacted as greatly as the roll-sensitive measures.

The variable pertaining to the G-seat produced extremely surprising results. While the G-seat produced significant effects in the first study on two maneuvers, the takeoff and the GCA, no significance was recorded in the second study. Reevaluation of the consistency of the results of Study I taken in light of Study II results revealed that although multivariate significance was achieved in those two instances only five univariate tests reached criterion significance in 19 total tests for the two maneuvers. This demonstration coupled with the very consistently small contribution of the G-seat in the second study suggests that the G-seat may be the least important variable of the system variables studied in these projects.

The interactive potential that the G-seat demonstrated in the first study was not realized in the second study. One possible explanation for the absence of this and other interactions involving the G-seat in the second study is that the research designs utilized in Study II were considerably more conservative than the research designs employed in the first study. This does not invalidate the former effort because the purpose in that study was to isolate and identify any and all possible sources of variance in an attempt to explore the variable space completely. Apparently, that study was successful in identifying all of the possible sources of variance. However, when these sources were scrutinized more closely, as in the second study, they were found not to be as important as formerly believed.

Another important area to which these studies have contributed substantial information is that of performance measurement. The existence and the nature of the subject effects and the system configuration variable effects have demonstrated the utility and efficacy of a comprehensive performance measurement strategy which addresses not only the traditional system output types of measures but also includes control strategy measures in the form of pilot workloads and input smoothness. The results of the two studies seem to suggest that given different conditions, expert pilots adapt to these conditions often without serious degradation in the vehicle's performance but frequently with radical changes in control strategy and information acquisition. These studies have begun to identify the manner in which these changes seem to occur. Obviously, the area requires more exploration to substantiate and refine the findings of this series of investigations.

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## *APPENDIX A:* DESCRIPTION OF PERFORMANCE MEASUREMENT ALGORITHMS

The performance measurement algorithms used in this study divided each maneuver into several exercise segments. For each exercise segment, special computer programs, labelled "cases," were developed that determined simulator system conditions and defined the parameters to be measured in that segment. The operation of these cases may be described in the following manner. An initialization case set the simulator at the maneuver starting conditions. Intermediate cases used to sample outputs executed a FORTRAN program with a 3.75 Hertz iteration rate. A special case was provided which measured the pilot outputs at an interation rate of 15 Hertz. An end-point case froze the simulator when the end conditions for the maneuver were met.

Descriptions of the performance measurement algorithms for the five maneuvers are as follows:

*GCA and Landing*: The starting condition was 2,400′ MSL, 300 degree heading, and 160 knots on an 8-mile final for Runway 30. The pilot maintained starting conditions until the Cognitronics Voice System began giving GCA "controller" instructions. The pilot slowed to 110 knots and lowered the landing gear and flaps at the appropriate airspeeds. He followed the "controller" heading instructions to maintain course. At 4.5 miles, the pilot intercepted the glidepath. The controller then provided information on aircraft position relative to the glidepath (above or below and left or right). When the pilot had the runway in sight, he made appropriate corrections to maintain the extended centerline and glidepath visually. The pilot was instructed to land on the runway centerline, approximately 1,000′ down the runway. The maneuver was terminated on landing roll after the airspeed decreased below 50 knots.

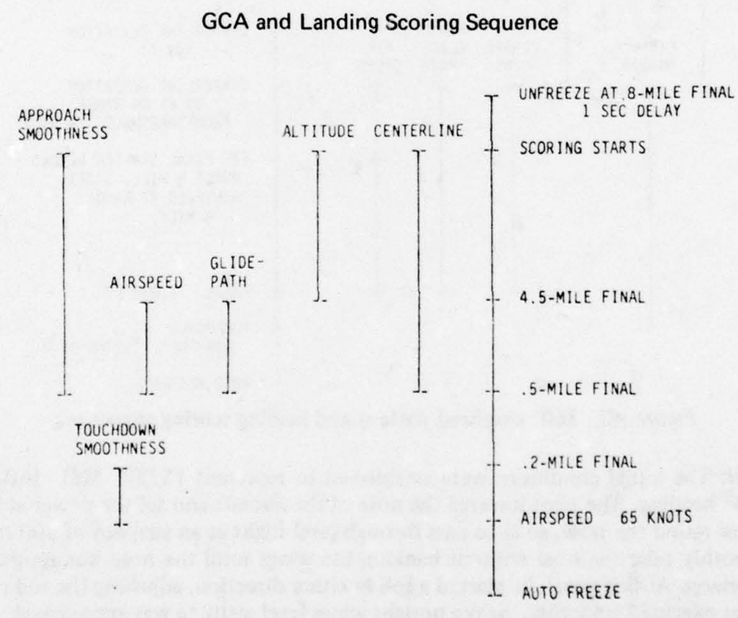


*Figure A1.* **GCA and landing scoring sequence.**

*360° Overhead Pattern and Landing*: The starting condition was 2,500′ MSL, 300° heading, and 200 knots on 4-mile initial for RW 30. The pilot flew the initial, maintaining altitude, airspeed, and runway centerline. Approximately halfway down the runway, the pilot pitched out by reducing power to 50–60% rpm and made a steep turn to the left not exceeding 60° bank. After completing a 180° turn, he lowered the speedbrake and landing gear, maintaining 2,500′ MSL and 120 knots minimum. Approximately 3/4

mile past the end of the runway, he lowered the flaps and started a descending turn to the left. He maintained 110 knots minimum and adjusted the bank and descent rate so as to roll out on runway centerline at 1,700′ MSL.

Once on final approach, the pilot maintained 100 knots minimum and a constant glidepath. He adjusted pitch and power so as to touchdown in the first 1,000′ of the runway at an airspeed between 75–80 knots. The maneuver was terminated when airspeed decreased below 50 knots during the rollout.

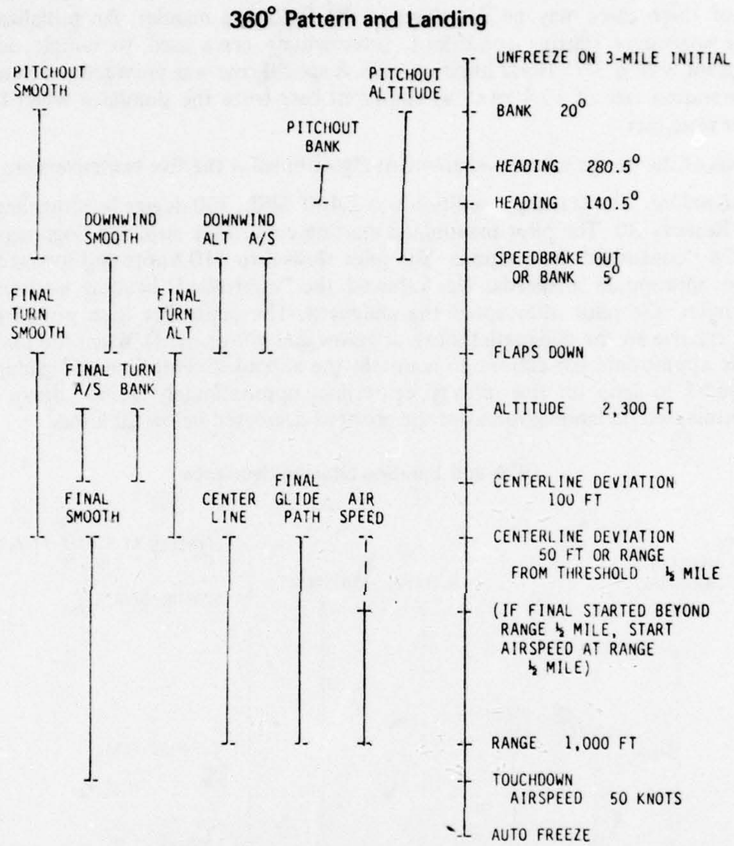


*Figure A2.* **360° overhead pattern and landing scoring sequence.**

*Aileron Roll*: The initial conditions were established to represent 15,000′ MSL, 160 knots indicated airspeed, and 180° heading. The pilot lowered the nose of the aircraft and set the power at 90% in order to accelerate. He then raised the nose, so as to pass through level flight at an airspeed of 200 to 230 knots. He continued to smoothly raise the nose without banking the wings until the nose was approximately 20° to 30° above the horizon. At this point, he started a roll in either direction, adjusting the roll rate as necessary so that the roll was executed smoothly. As the upright wings level attitude was approached, aileron pressure was gradually released to roll out with the nose on the horizon. The exercise was terminated 5 seconds after the roll was complete.

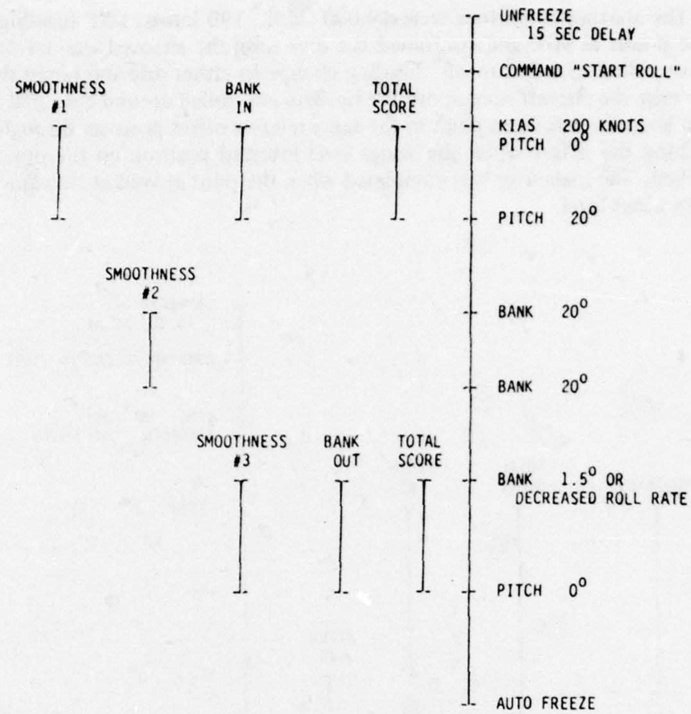


*Figure A3.* **Aileron roll scoring sequence.**

**1. *Loop*. The starting condition was 15,000′ MSL, 160 knots, and 180° heading. The pilot lowered the nose of the aircraft to accelerate while setting power at 100%. He then raised the nose so as to pass through level flight at an airspeed between 240 and 250 knots. He continued to raise the nose vertically with a constant positive 3 "G" force and maintained wings level. At the top of the maneuver, while inverted, stick back pressure was reduced to keep a constant pitch rate change. As airspeed increased on the downward part, stick back pressure was increased to keep the pitch rate constant with the wings level. The maneuver was terminated when straight-and-level flight was reestablished.**

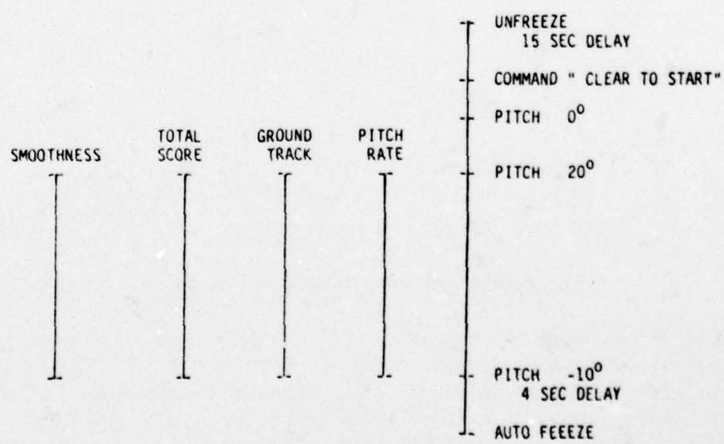


*Figure A4.* **Loop scoring sequence.**

2. *Barrel Roll*: The starting conditions were 14,000' MSL, 190 knots, 180° heading, and a 12° dive angle. The pilot set the power at 90% and continued the dive until the airspeed was between 200 and 230 knots indicated. He then rolled to a 30° to 45° heading change to either side and raised the nose to wings level. He continued to raise the aircraft nose above the horizon and rolled around a desired reference point. The pilot attempted to keep the reference point in the same relative offset position throughout the roll. He continued the roll checking the offset when the wings level inverted position on the opposite side of the starting point was reached. The maneuver was completed when the pilot arrived at the same position where he initiated the roll with wings level.

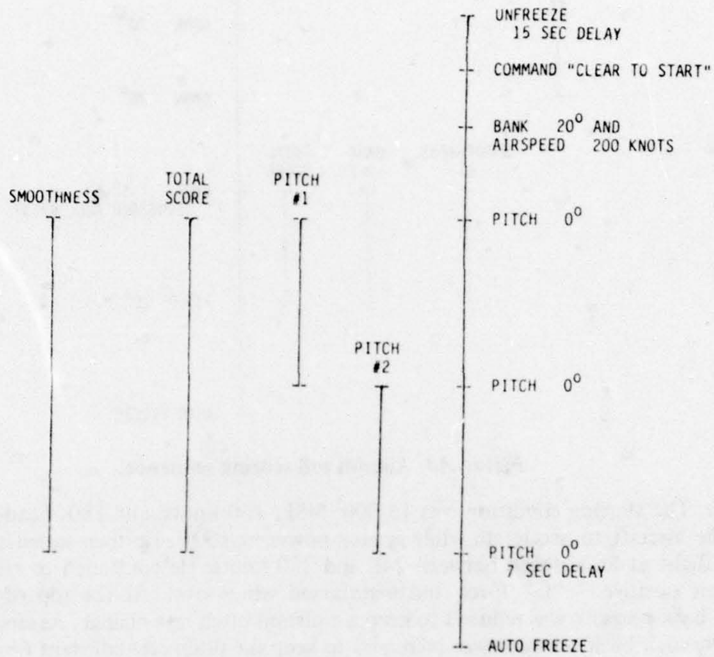


*Figure A5.* **Barrel roll scoring sequence.**


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